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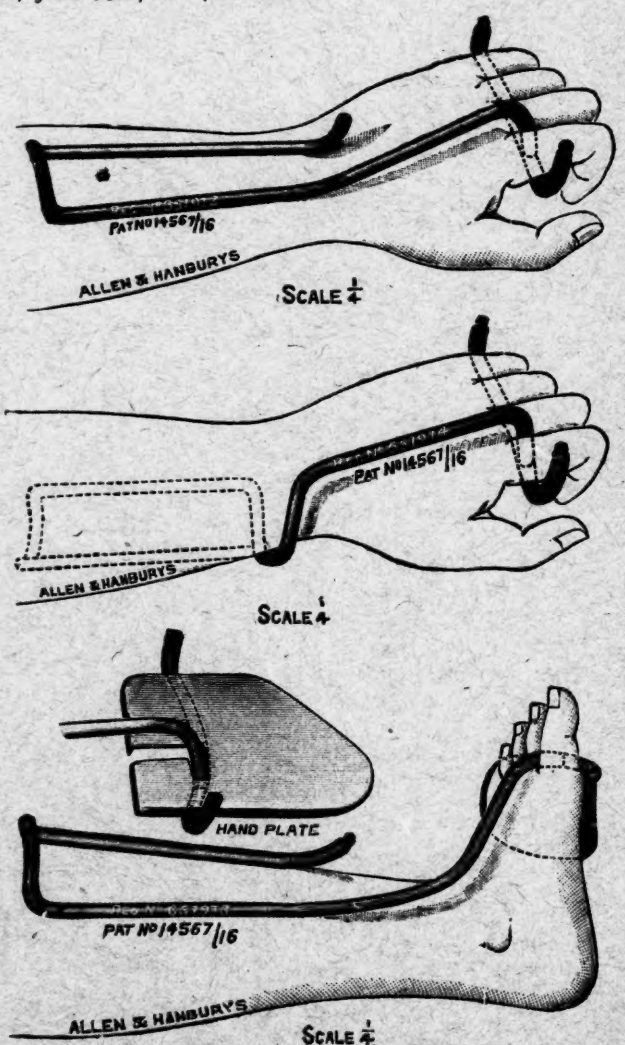

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JOHN HALLE.

1529–1568.

JOHN HALLE belongs to that band of educated surgeons who endeavoured during the reign of Elizabeth to raise the status of surgery in England and to restrain quacks. Vicary, Gale, Clowes, Banister, and Read were the leading spirits in the crusade—all men worthy of the utmost reverence from us, their successors; for when the lamp of surgery was burning very dimly in England, they replenished it and handed it on newly trimmed. Vicary, Gale, and Clowes were London surgeons; Halle, Banister, and Read practised in the provinces, yet were in close touch with their colleagues and friends. They formed a little band, working to a common end and introducing each others books with eulogies in very bad verse. All were members of the United Company of Barbers and Surgeons created in 1545; indeed it is possible that the union of the Guild of Surgeons and the Company of Barbers was in part due to the direct efforts of the older members.

Halle and Read have proved themselves the most elusive of the band; of Vicary, Gale, and Clowes some memorials still exist. The utmost diligence of Mr. J. H. Allchin, the Chief Curator and Librarian of the Museum and Public Library at Maidstone, only shows that Halle was implicated in Wyatt's Rebellion in 1554, for which he was imprisoned but subsequently pardoned and released; that he died in October, 1568, at the age of 39; and that he was buried in All Saints' Church in his native town. From his own writings, we know that he practised in Maidstone, where he was held in respect by his fellow-townsmen; that he was a stout Protestant, as might have been expected from his implication in Wyatt's rebellion; that he was married, his wife dying on June 16 (? 1561); that he was gifted with a keen sardonic humour; that his beard was black and he was of a choleric temperament.

The work done by Halle in his short life was considerable, and he must have begun it early, for in 1550 he complains that "certayne chapters taken out of the Proverbes of Solomon with other chapters of Holy Scripture and certayne Psalmes of David translated (by him) into English metre" had been unfairly attributed to Thomas Sternhold, and at this time he was not more than twenty years old. His extant works are:—

1. A small quarto volume, "imprinted at London in Flete Streate nyghe unto Saint Dunstanes church by Thomas Marshe An. 1565," containing: (*a*) A translation of Lanfrank's smaller surgery; (*b*) An expositive table of the strange words used by Lanfrank, amongst which is 'algebra': "This Arabye worde Algebra sygnifieth fractures (as of bones &c.)"; (*c*) A treatise of anatomy, in three parts; (*d*) *An Historiall Expostulation against the Beastly Abusers bothe of Chyrurgerie and Physyke in oure time.* The last tract is priceless as a picture of the times, and of Halle's method of treating quacks. It was republished by the Percy Society in 1844, when it was edited

by T. J. Pettigrew. Prefixed to this volume is a portrait of John Halle, with the date 1564 and the inscription "J. H. anno ætatis suæ 35." It represents him with a jewelled ring on the right index finger, wearing the cap of a Master of Surgery, and in his hand a sprig of vetch.

2. In the same year he issued *The Courte of Vertue containing many Holy or spiritual songs, sonnettes, psalmes, Ballets and short sentences as well as of Holy Scriptures as others with Music notes*, 16mo. The *Courte of Virtue* is nearly as good as the *Historiall Expostulation*, and it is one of the class of books which made the early puritans acceptable to the people, for it set the scriptures to tunes which could readily be sung, whilst it satirized with no sparing hand the foibles of the time.

3. A volume of manuscripts which once belonged to John Halle still remains unpublished at the Bodleian Library. It contains amongst other things a translation of Benedictus Victorius on Syphilis, conceived on the same lines as the translation of Lanfranc.

Halle says of the Lanfranc, that "it was translated oute of French into the olde Saxony English about two hundred years past, which I haue nowe not only reduced to our usuall speache by changying or newe translating suche words as nowe be inveterate and growne oute of knowledge by process of tyme, but also conferred my labours in this behalf with other copies both in French and Latine; namely with Maister Bacter for his latine copy and Symon Hudie for his french copie and other English copies of the which I had one of John Chamber and another of John Yates both very ancient." A comparison of Halle's translation with the editions of Lanfrank published in 1380 and 1420 shows that it does not correspond with either, even if allowance be made for a process of severe editing at Halle's hands. The statement is valuable, because it gives a possible clue to the mystery surrounding the origin of *The Englishman's Treasure* published by Vicary a few years earlier.

The *Anatomy* is a mere compilation of mediæval knowledge, without reference to the newer teaching of Vesalius which had already been accessible for nearly a quarter of a century. Halle says that he was encouraged to publish it "by the example of good Maister Vicarie, late sargeaunte chirurgian to the Queen's highness who was the first that ever wrote a treatyse of Anatomye in English (to the profite of his brethren chirurgians and the helpe of younge studentes) as farre as I can learne."

The real value of Halle's work lies in his determined attempt to advance the social position of the surgeon, by insisting upon a higher standard of education for the apprentice, a knowledge of medicine as well as surgery by the practitioner, and a rigid suppression of quackery by the United Company. The union of Barbers and Surgeons was still so recent that the commercial spirit of the Barbers remained in the ascendant, and the United Company was rather too ready to increase its numbers without regard to the education or even to the character of the candidates for admission. Medicine had become entirely divorced from surgery, and in the absence of scientific knowledge quackery was rampant. Each of these conditions is amusingly exposed in Halle's writings. He says, in reference to the apprenticeship system: "For truly there are many that take servauntes and apprentices not for to teach them science but only to be their drudge and to doe their toyle and labore,

JOHN HALLE.

Reproduced from the frontispiece of Halle's translation of Lanfrank's smaller surgery.

which is the cause that so many come oute of their yeares so ignoraunt. For their interest is to have servauntes to dooe their toyle in their house and not to make them cunnyng men; yea, and some will refuse a young man that is learned and apt to understande to have an ignoraunte slave to beare the water tankard and scoure pannes; such an one (as the common proverb is) that will never doe a man of science harme unles he steale away his dynner."

The antagonism of medicine to surgery is referred to in the following manner: "For as physicians thynke their learning sufficient without practice or experience so the chirurgien for the moste parte, having experience and practice, thinketh it unnedeful to have any learning at all which also hath boldened every ignoraunt, rusticall, yea, and foolish woman to think themselves sufficient to professe and worke in so noble and worthy an arte."

The attempt to consolidate medicine and surgery failed, as it had already failed in 1421, and only became an accomplished fact in England in 1886, when the Royal College of Physicians agreed with the Royal College of Surgeons to establish a conjoint examination. The efforts of Halle and his friends bore some fruit, however, for in 1566, the year after the *Historiall Expostulation* was published, Thomas Hall—his younger brother—was given an Exhibition by the Barber Surgeons of 40s. "towards hys studie in the Unyversitie for surgery annexynge physicke thereunto and thereby to profit his other brethren by readynge lectures unto them in the Comon Hall." Thomas Hall made good use of the start thus given to him. He was of Broadgates Hall, Oxford; obtained a licence in medicine March 17, 1571–2; was appointed Dissector of Anatomy at the Barber Surgeons' Hall in 1577; graduated M.D. at Oxford in 1581; and was chosen a Fellow of the College of Physicians in 1585.

Writing of quacks, John Halle says: "Ther came into the towne of Maydstone in the yere of our Lorde, 1555, a woman whiche named hir selfe Jone, havyng with hyr a walkyng mate whom she called her husbande. This wicked beaste toke hir inne at the sygne of the Bell where she caused to be published that she coulde heale all manner both inward and outward diseases. This beastlie deceaver amonge manie others, tooke in hand an honest mans child who had a suppurat tumour in his navell, percynge dangerously the panicles of the belye, to whom she administered a powder [made of the herbe daphnoydes and anise seed together] in great quantite in so much that the childe dyd vomite continualle for the space of halfe a daye and more withute ceassynge whereby the said aposteme brake. The childis parentes did send for me to know therein myne opinion and counsell: unto whom I prognosticated (as I sawe good cause) that the matter was very dangerous and not lyke to be cured. But this beastly forme of a woman hearyng me so saye answered that she douted therein no daunger and farthermore offered hirselfe to be locked up in a chamber with the chylde and that yf shee healed him not shee myghte be punished; with a great deal more circumstance of prating and dyceytfull braggynge wordes. Unto whose moste wicked and divlishe boldness I thus answered. Wher as you saye that ye doubte not any daunger in this childe I verye well beleve you, for ignorante fooles can doubte no perils, and who is bolder than blynde bayerd? how shoulde they doubte that knowe not what a doubt meaneth? Nothwithstandynge,

this preheminence you deceavynge rennegates have, ye maye bragge, lye and face tyll ye have murdered or destroyed suche as credyte you and then are ye gone, ye shewe your heles and that is onelye your defence. But honest menne of arte muste have truthe for theyr defence and maye promyse no more than they may performe.

"What should I make manye wordes, the parentes of the childe all to late discharged this deceaver and the child, notwithstandyng the counsell had of dyvers learned men, dyed afterwards of the sayde grefe. But the sayde deceaver accordyng to my prophesie, after iij. dayes ran away, she and her walkying mate robbynge their hoste where they lay of the shetes, pillow-beres and blankets that they laye in and they hadde muscadell served them instede of bere whyle they laye there for the moste parte.

"Secondly in the yere of our Lord 1556 there resorted unto Maydstone one Robert Harris who could tel by only lokyng in ones face all secrete markes and scarres of the bodye and what they had done and what hadde chaunced unto them all theyr lyfe tyme before. . . . . Well for jestyng a lyttell agaynste the madnes of thys deceaver, I hadde a dagger drawn at me not longe after." Halle's jesting on quacks was mordant, so the attempt on his life was well justified in the eyes of his victim.

"Thyrdlie in the year of our Lord a thousand fyve hundred and fyftie and eight there came to Maydstone one Thomas Lufkyn the beastliest beguiler by his sorcerys that ever I herd of, making physike the onely colour to cover all his crafty thefte and mischieves. This vileyne coulde wyth a wodden face bragge, face and schoute his maters wyth bould talke that the symple people wer by him marvelously seduced to beleve his lies and boastinge tales.

"Fourthlye in the yeare of our Lorde a thousand fyve hundred and three score, one Valentyne came into a parish in the wolde of kente called Staplehurst callynge hymself Master Wynkfylde affirmynge hymselfe to be the sonne of a worshipful knight of that name. But as tyme revealeth all thynges so this devylyshe beaste in shorte tyme was knowne in his righte kynde and name: and that he had iij wyves lyving at that present, of which the first lyved very poorelye and myserably in Canterbury: the second after she knewe his wickednes, departed from him and maried after with a preste: the third which he at that present had, he maried at Westmynster, being there a riche widowe."

So there are many other entertaining accounts, full of detail, about quacks and their ways; but in the end Halle returns to his original theme, and declares his faith in these words: "As I would therefore that all chirurgians shoulde be learned, so woulde I have no man thinke him selfe lerned otherwise than chiefly by experience; for learning in chirurgery consisteth not in speculation only, nor in practice only, but in speculation well practised by experience. Therefore when we saye that a chirurgian muste firste be lerned and then worke, it is not ment that any man by the reading of a booke or bokes onlye, may lerne how to worke for trulye that hath caused so many deceivinge abusers, as there are at this daye."

METHODS AND RESULTS OF TRANSPLANTATION OF BONE IN THE REPAIR OF DEFECTS CAUSED BY INJURY OR DISEASE.

By ERNEST W. HEY GROVES.

I.—HISTORY AND LITERATURE.

The transplantation of bone, depending as it does upon the fundamental facts of bone structure and growth, has been the subject of much experimental and clinical work, which during recent years has received a great impetus by reason of the improvements of surgical technique and the possibilities of excluding septic infection. But although many painstaking observations have been made, the theoretical aspect of the question is still a matter of strongly divided opinion. So divergent indeed are the views held by leading workers, that a feeling something akin to despair is aroused in the mind of the seeker after truth—not so much by mere differences of opinion amongst the observers, but by the apparent contradiction of the facts observed. Yet in sharp contrast to the antagonistic state of opinion about the theory of bone growth, there has slowly emerged a most healthy and encouraging unanimity in regard to the practical aspect of the subject. This leads to the conclusion that, as the preliminary collection of experiences and observations has afforded foundation for a very solid superstructure of practical results, therefore the foundation must after all be both solid and lasting. And instead of giving up in despair all attempts to reconcile conflicting evidence, the student is encouraged to go back and examine piece by piece the work that has been done; and he will certainly be rewarded for this by finding that in reality truth itself has been immutable, and differences of opinion have arisen from the bias of preconceived views, and from a narrowness of outlook which can now be corrected.

Havers,[1] whose name has ever since been identified with the vascular canals in bone, in 1692 gave the first accurate account of osseous structure, and he described the periosteum as simply a connective-tissue, limiting, and vascularizing membrane. Antoine de Heyde[1] in 1684 published the first experimental observations, made on frogs, and came to the conclusion that callus was formed by calcification of blood-clot extravasated round the broken bone ends.

It was, however, in the middle of the eighteenth century (1739–1743) that the first systematic work on this subject was carried out by Duhamel,[1] who was the originator of the modern, generally accepted theory of the function of the periosteum. In his view the periosteum became thickened and succulent round a fracture, and by pushing the new tissue in amongst the fragments it formed the callus. He it was who founded the term 'cambium

layer' of the periosteum which is now in every-day use, especially in German literature. Eighteen years later, Troja[1] produced experimental necrosis of the long bones by introducing foreign bodies into the medullary cavity, and described the formation of new bone between the periosteum and the dead shaft.

A century after Duhamel, after many less remembered works and discussions on the subject had appeared, came the great work of Ollier[2] (1867), which remains to-day a classic of surgical literature. Ollier's work was so thorough and so careful, that his conclusions have attained an almost unassailable position. Unfortunately, that part of his work which related to the apparent osteogenetic function of the periosteum has taken so firm a hold upon surgical teaching, that the remainder has been overlooked or forgotten.

During the last fifty years, as a part of the growth of modern surgery, many experimental and clinical observations have been made as to the behaviour of transplanted bone and the results obtained by its use. For the most part these have been isolated examples, often regarded as curiosities or rarities of surgical daring, not calculated to lead to any practical modification of routine surgical practice. But there have been three men since Ollier whose work has marked an epoch in our knowledge. These are Barth, Axhausen, and Macewen.

Barth[3] in 1893 showed that in spite of the smooth healing of bone-grafts, the greater part of the cellular contents of the transplanted bone underwent necrosis, and he went so far as to deny that there was any difference between the behaviour of a graft of living bone taken from the same animal, that from another animal, or boiled and devitalized bone. But as he has since abandoned this extreme view, we may ignore it, whilst still placing to his credit the observation of the fact, now generally admitted, that the greater number of the cells of the compact tissue of a bone-graft actually die.

Axhausen[4] in 1898, dominated by the idea—then universally held—that the periosteum was the principal agent in osteogenesis, collected a number of clinical and experimental facts which he took to prove that both the periosteum and the endosteum in grafts survive transplantation, though the cells of the compact bone die. His evidence was so convincing that Barth abandoned his idea of a bone-graft being a dead scaffold, and admitted that a living, periosteum-covered graft took an active share in bone regeneration.

Then, in 1911, Macewen produced his work *The Growth of Bone*,[5] which with direct and almost staggering simplicity tended to overturn all our views of osteogenesis. He denied that the periosteum was anything but a limiting membrane, and he ascribed to the osteoblasts all the phenomena of bone growth and repair. Unfortunately Macewen was content to record his own observations, without attempting to explain their apparent discrepancies with those made elsewhere, and it has been left for others either to attempt this task, or to content themselves with tabulating lists of divergent views, and the apparently contradictory facts upon which these views are founded.

Since the appearance of Macewen's volume, many other papers have appeared, for the most part confirming what he demonstrated, but to some extent confuting it. It seems quite possible, however, at the present moment

to collect together the principal writings on this subject, and by a critical examination of the facts presented, to build up a perfectly consistent narrative of the sequence of events in bone growth in relation to grafting. Although at present the opinions of the various protagonists may appear to be widely divergent, yet all the facts upon which they base their conclusions are susceptible of a harmonious interpretation. In the attempt to make this critical examination, it will be convenient to summarize the work of Ollier, Barth, Axhausen, and Macewen, then to present a unified statement of the stages in the history of a bone-graft as deduced from these observations, and lastly to refer briefly to some of the other more recent literature in its bearing upon the points in question.

Ollier's Work.

Ollier has embodied his observations in two volumes, entitled *Traité Expérimental et Clinique de la Régénération des Os*, published in Paris, 1867.

It will only be necessary for the present purpose to summarize the contents of the first volume dealing with the experimental work. The clinical practice of those days, not being subject to confirmation either by the microscope or by the *x* rays, does not lend itself to critical examination. His experiments were performed mostly on quite young dogs and rabbits. His actual observations were as follows :—

1. A flap of periosteum lifted from the tibia, but left attached at its base to the bone, turned round a muscle, produced a ring of bone.

2. The same experiment was repeated, but the base of the flap was divided after four days : a bony ring was formed.

3. A flap of periosteum, taken from the tibia, and transplanted into the frontal region, within forty days formed a new bone with a distinct medullary cavity.

4. A dura-mater flap, transplanted into the groin, produced a scanty bone deposit.

5. A flap of periosteum, if scraped on its deep surface, does not produce bone.

6. An emulsion made from the scrapings from the deep surface of the periosteum, transplanted into the thigh, produces small bone nodules.

7. In the formation of new bone from periosteum, sometimes cartilage precedes bone formation and sometimes not.

8. A mild degree of suppuration does not prevent osteogenesis.

9. Free transplantation of marrow tissue does not produce new bone.

10. After amputation through the middle of a long bone, a thin metal cylinder was introduced into the marrow cavity, and this became filled with new bone.

11. If the periosteum is stripped from a bone, the latter regenerates a new periosteum.

12. If, after the removal of the periosteum, the bone is scraped, the formation of new periosteum is prevented or retarded.

13. New periosteum formed from old bone can also in its turn reproduce new bone, though not so freely as in the case of normal periosteum.

14. If bone is deprived of its periosteum, it continues to live, and increases not only in thickness but in length.

15. If bone is deprived both of its periosteum and its marrow, it continues to live, and its ends undergo hypertrophy.

16. If bone is deprived of its periosteum and is surrounded by metal foil, it still grows in thickness, by encroachment upon the marrow cavity.

17. Bone deprived of its periosteum and then fractured, unites by a process of normal callus-formation.

18. Section of the nerves produces no effect upon the healing of fractures.

19. When a whole bone is removed subperiosteally from a young animal, a new bone is reproduced, which is longer and thicker than that removed.

20. If a whole bone is removed with its periosteum, no new bone is reproduced.

21. If a joint is resected in a young animal, with preservation of the capsule, the joint is reproduced. This succeeded best in the elbow and the knee.

22. The above experiments with young bones succeeded equally well with long bones, flat bones (scapula), and short bones (os calcis).

23. In an adult dog, subperiosteal resection gave no new bone.

24. In an adult, if, prior to resection, the periosteum is stimulated (by cutting the periosteum and boring the medulla with a stylet), then a little ossification results after resection.

25. If after subperiosteal resection the resected part is replaced, a more massive bone than before is produced. He attributes this to irritation of the periosteum, and says that the same thing happens if a foreign body is made to replace the resected bone.

26. He confirmed the experiments of Hunter and Flourens proving that the growth in the length of bone is from the ends of the diaphysis, and showed that in all long bones the rate of growth is always much greater at one end than at the other.

27. The growth of cartilage is interstitial.

28. Destruction of the epiphyseal cartilage prevents the growth of a bone in length.

29. Bone formed from a free transplantation of periosteum is absorbed after a short time.

30. Periosteal new bone can be grafted from one animal to another of the same species.

31. Whole bones can be grafted from one animal to another of the same species. In such a case the graft grows in thickness, but not in length, and the graft remains vascular.

32. Fragments of bone, without periosteum, will live when grafted. Ollier thought that this only took place after vital connection had been established between the grafts and the periosteal or marrow tissue of the bed.

Ollier's investigations were thus much more extensive and his views much wider than they might be judged from quotations in recent literature. As far as they go, his experiments and figures are beyond criticism, but the histological aspect of the subject was not touched upon, neither of course was any radiographic evidence available. That he took an exaggerated view of

the rôle of the periosteum may be true, but nevertheless he quite clearly states that the periosteum in flaps or in transplants is only fully osteogenetic in young animals, and that it is not so in adults. He points out that the compact bone can live, grow, and undergo repair, quite independently of its covering membrane, and he shows that osteogenesis lost in the adult periosteum could be revived by stimulation of the compact bone beneath; he proved the viability of autogenous and homogenous grafts, and he recognized that separate living bone fragments without periosteum could live and grow in a suitable environment.

Barth's Work.

Barth's[3] researches have nothing like the same importance as those of the other three pioneers; but they have had a very wide influence, both in founding the idea that bone-grafts simply act as a passive scaffolding, and in stimulating further research such as that of Axhausen, which has given us a much fuller knowledge of the details of bone regeneration.

Barth's first papers (1893) are concerned with the microscopic appearance of pieces of bone placed in trephine openings in dogs' skulls. In most cases a trephine disc was immediately replaced, but in others a bit of sterilized macerated bone was used to fill the gap. His findings may be summarized as follows:—

1. To the naked eye there is no difference between the behaviour of dead and living bone-grafts when observed after comparatively short intervals (13–61 days).

2. The whole of the substance of the compact bone of a graft dies, judging from the empty cell spaces.

3. There is great proliferation of connective tissue (i.e., granulation tissue) from the outer surfaces of the dura mater. Between this and the graft there appear islands of new bone and areas of callus formation. (This is only shown in his figures in the case of living bone-grafts.)

4. There is absorption of the dead tissue of the bone-graft, and a formation of new bone, which grows into the graft from the surrounding living bone.

5. New bone is also deposited in marrow spaces of the graft where these lie open and exposed to living tissue.

6. New bone makes its appearance in and around the Haversian canals of the dead bone.

Upon the somewhat slender foundation of these observations, Barth proceeded to build the superstructure of his theory that, for grafting purposes, autogenous living bone, with or without periosteum, and homogenous, heterogenous, and macerated dead bone, all behave alike. The value of his observations in relation to the general subject of bone-grafting is vitiated by the following facts: (*a*) They are founded on the study of the skull; (*b*) They only cover very short periods; (*c*) He assumes, without sufficient evidence, that new bone formation in relation to a living graft all comes from the surrounding bone and not from the graft itself. He actually figures the following elements of new bone formation: callus between the dura and the graft; callus between the graft and the surrounding bone; new bone tissue in the enlarged Haversian canals and in the marrow tissue of the graft. Clearly any or all

of these elements of new bone may have been derived from the living graft, a suggestion which is supported by the fact that they are either absent or not apparent in his own figure of the transplantation of a dead bone.

But though Barth himself has abandoned the view that a dead and a living graft behave in the same way, yet his work has established the facts that a graft is slow and indolent in the matter of growth, that the greater part of the compact bone dies, and that final success in grafting depends very largely upon the intimate contact of the graft with the living vascular bone of its bed.

In 1908 Barth[6] admitted that living periosteum-covered bone was the best graft material for securing active new bone formation, but he maintained that, for the mere filling of holes in a skull or the long bones, dead bone chips or bone dust formed the best material. He relates a remarkable case of a girl of 17, who had had multiple spontaneous fractures. He treated these on different occasions by open osteotomy, filling the marrow cavity with dead bone dust (*knochen kohle*), with uniform success. This observation will be referred to later.

Axhausen's Work.

In 1908 Axhausen[4] published a most careful and exhaustive paper giving an account of 146 animal experiments in bone-grafting, together with a very detailed histological account of his findings. His experiments included transplantation of pieces of bone into the soft tissues, and into other bones; autoplastic, homoplastic, and heteroplastic grafting; grafting of bone with and without periosteum and marrow; and grafting of boiled bone. He carried out these experiments with rats, rabbits, and dogs. His work contains such a wealth of detail that it is difficult to do justice to it in a summary. The following are his chief points:—

1. A living periosteum-covered graft shows marked cellular proliferation under the periosteum.

2. A graft containing marrow shows new bone formation from the marrow tissue wherever this is in contact with living vascular tissue.

3. The compact bone of a graft, whatever be its source, always exhibits empty cell spaces in the greater part of its extent.

4. The disappearance of the cells from the compact tissue of a living graft proceeds from without inwards, and is preceded by a shrinking and deformity of the nuclei.

5. He admits, however (p. 120), and figures (*Fig.* 9, *Pl.* 2), that certain areas occur in the edge of the compact bone where the cells retain their staining properties. This was seen best in the pieces of bone close to areas of periosteum or marrow which had retained their vitality. He admits that it is uncertain whether such areas may represent foci of new bone production, though he assumes in his conclusions that they do not.

6. The dead compact bone is rebuilt by successive stages of absorption and apposition of new bone formed beneath the periosteum, from the marrow tissue, and in the channels made by new vessels which penetrate the old dead bone.

7. He figures (e.g., *Fig.* 17, *Pl.* 4) new bone laid down round vessels in the widened Haversian canals of the graft. It is not clear why he assumes

that these have all grown in from outside, instead of having arisen from survivals of the cells of the original compact bone.

8. The periosteum has a capacity for survival, proliferation, and production of new bone, but it does not survive in those parts where muscle tissue or blood effusion prevents its organic growth to surrounding tissues.

9. At the cut edge the periosteum shows a more marked tendency to proliferation than elsewhere. Longitudinal incisions of the periosteum increase subperiosteal new bone formation.

10. The marrow is also osteogenetic, but only where it is in immediate contact with living tissues, i.e., at the cut ends or along a split bone.

11. Bone taken from another individual of the same species shows exactly the same behaviour as one taken from the same individual, but the viability and osteogenesis are both of a lesser degree.

12. Bone grafts without periosteum are far inferior to those covered with periosteum, both in viability and osteogenesis.

13. He admits, however, the viability of pieces of nude bone, saying that survival depends upon retained marrow tissue and on the existence on the outer surface of irregular deposits of " osteogenetic layers of the periosteum," from both of which new bone is laid down.

In 1911, in a later paper,[7] Axhausen adds certain valuable observations of a clinical character, and he summarizes the differences between his views and those of Barth. In a patient, age 23, a graft of the periosteum-covered fibula was implanted in the shaft of the femur, the upper part of which had been resected for a fibroma. A marked increase occurred both in the thickness and density of the graft, but this only began after five months, and was rapid between the twelfth and eighteenth month. He holds that this delay was due to the time taken by the substitution of the dead compact bone by the periosteal new bone. In a second case, a man of 31 had a piece of tibia grafted in place of a metacarpal. After sixty days it became dislocated, and the end had to be removed. This specimen confirmed his experimental findings—i.e., there was marked proliferation of cells under the periosteum, and especially at its cut edge ; the great mass of compact bone showed empty cell spaces ; and at the cut edge of the bone there was marked lacunar absorption and substitution.

The great and lasting value of Axhausen's work is the wealth of detail which he gives of the microscopic processes in bone-grafting. His inferences from, and interpretations of, the structure he describes are often open to criticism. That the greater part of the compact tissue of the graft suffers the loss of its living cells is fully conceded now by all authorities, but as Frankenstein, Woolf, and David have all pointed out, a certain number of cells appear to survive, and these are actually shown in Axhausen's own figures. Then, again, the assumption that the new bone cells in the Haversian canals have all migrated into the bone from outside the graft is by no means proved. That Axhausen is so strongly biased by a preconceived idea of the osteogenetic function of the periosteum as to be incapable of taking a fair view of matters relating to it, is shown by the remark (*Archiv. f. klin. Chir.*, 1911, vol. xciv, p. 277) that no tissue could be regarded as periosteum unless its osteogenetic function could be demonstrated !

Macewen's Work.

Macewen's[5] conclusions were the result of a very long and wide experience of the clinical events in bone surgery, and of animal experiments, chiefly upon dogs. His principal observations are as follows :—

1. Young dog's radius : resection of part of the whole thickness of the bone, leaving the periosteum. No bone was formed by the periosteum in ten weeks, but the gap was nearly filled by epiphyseal growth pushing the two ends towards the gap, and by proliferation at the cut ends of the bones.

2. Young dog's radius : resection of the whole bone, including the epiphyseal cartilages, but preserving the periosteum No new bone formed in six weeks.

3, 4. Failure of periosteal flaps to produce new bone.

5. Free periosteal transplant produced only a small nodule of bone in five weeks.

6. Removal of the entire periosteum did not affect the life and growth of the bone.

7, 8, 9. Silver rings, placed round a bone bereft of its periosteum, became buried in new bone, which must have arisen from the compact bony tissue.

10, 11. Portions of the radius from two different dogs removed, broken into pieces, and replaced, exchanging the bone of the two dogs. This was done after removal of the periosteum. Yet a massive piece of new bone was formed in each case. (In both cases there is very marked hypertrophy of the bone into which the graft is made, and in one—*Fig.* 15 in Macewen's book—the massive bone is shorter than normal. These points will be discussed later.)

12, 13. Homoplastic grafts of the whole radius without its periosteum exchanged between one dog and another. Perfect union, accompanied by decided thickening of the bones, occurred after eleven weeks.

14, 15. Shavings of nude bone placed in a gap in the radius in two young dogs. In both cases a big mass of new bone was formed. (As in 10 and 11, the original bone fragments are much thickened, but the bone as a whole is shorter than normal—in one case by a quarter of an inch, and in the other by five-sixteenths of an inch, in a five-inch bone.)

16, 17. Nude bone shavings implanted into muscle and peritoneum survived, growing in one case but atrophying in the other.

18. Transplantation of bone dust showed no bone growth.

19. Bone tissue was demonstrated growing into a piece of decalcified sponge placed in a bone gap.

20, 21. A glass tube was placed over the cut end of a bone, and bone tissue demonstrated growing into the glass tube.

22, 23. Free bone growth apart from periosteum was demonstrated in two human cases. In one it formed inside an aneurysm, the parent vessel of which had been perforated by a bone spicule. In the other it was formed in muscle in relation to a fracture.

24. A piece of bone was removed with its periosteum from the radius of a young dog. The gap became filled up, and the new piece of bone proliferated among the muscles surrounding it.

25, 26. Firm bone growth following re-implantation of skull fragments in

human subjects ; in one case the piece was replaced as a mosaic, and in the other as a whole fragment.

27. Subperiosteal resection of the radius, leaving a quarter of an inch of diaphysis at each end. After six weeks the shaft was re-formed. In the operation the upper epiphysis had been damaged, and from this the growth was weak ; from the uninjured lower epiphysis it was vigorous.

28. Removal of the periosteum of the radius and resection of all the diaphysis except its two ends ; the ends of the bone were capped with metal caps. After seven weeks the bone was re-formed, and the metal caps had been pushed past one another.

29, 30. Growth in length of bones arrested by excision of epiphyseal cartilages.

31. In a boy, the humerus was lost by osteomyelitis. No new growth occurred. On three different occasions several bits of bone from other children's tibias were inserted, each graft being about $1\frac{1}{2}$ in. long. Thirty years later the humerus was entire, 11 inches long ; the grafted portion could still be distinguished as a part $4\frac{1}{2}$ in. long near the lower end of the new bone.

32. Girl's jaw replaced by naked rib fragment with successful result.

Macewen's work derives great force from its very terseness and simplicity, and also from the association of experimental with clinical teaching. Its great lack is the absence of microscopical detail.

At the risk of making the present paper a bald reiteration of the work of others, I have set out above the main facts observed by Ollier, Barth, Axhausen, and Macewen, instead of merely giving their opinions and deductions. In this way only is it possible to examine the question of the unity of their discoveries, or to attempt to reconcile the divergences of their deductions.

AN ATTEMPT TO RECONSTRUCT A NARRATIVE OF BONE GROWTH FROM THE WORK OF THE FOREGOING AUTHORS.

1. **The Rôle of the Periosteum.**—We are met at the outset with the difficulty of one series of subperiosteal resections producing new bone and another producing none. But this is really not difficult of explanation.

a. In the first place, Ollier himself observed (obs. 23, *supra*) that periosteum formed no new bone in an adult after resection.

b. Secondly, in the case of a young bone, when a portion of its whole thickness is removed, leaving the periosteum, after a short time the gap is filled with new bone. All agree about this ; but as Macewen has shown, the filling of the gap may come from two sources other than the periosteum, viz., from the epiphyseal cartilage pushing the cut fragment towards the gap, and from proliferation from the cut ends of the bone. Therefore all experiments of this nature have no bearing on the osteogenetic function of the periosteum, since a gap in a long bone can be equally well filled up after that membrane has been removed, provided the epiphyseal cartilages remain intact (Macewen, obs. 28).

c. The most difficult facts to reconcile are the subperiosteal resection of a whole bone being in one case followed by regeneration and in one not. (Compare Ollier, obs. 19–21, with Macewen, obs. 2.) However, both authors clearly indicate the explanation. Ollier showed that if the periosteum was used

without its deep layer, then no bone was produced even in young animals (obs. 2); again, in adult bones, when periosteum would not produce new bone, this could be brought about by a stimulation of the dense bone by cutting and drilling, after which the periosteum left after resection would produce some new bone. Macewen, on the other hand, says that if bone is produced by a periosteal flap, this is due to the superficial layer of bone having been raised with it. Therefore, in reality, there is a middle or cambium layer lying between the bone and the periosteum in young animals. In such it is possible to raise the periosteum with the cambium layer attached, and it will reproduce the bone; or to dissect it off, without taking the deep tissue, and then it produces nothing.

d. In regard to free transplantat on of periosteum, there is less sharp divergence of results. For Ollier admits that bone formed from free periosteal transplantation becomes absorbed in a short time, whilst Macewen notes that a scanty bone growth is found in a periosteal flap taken from a limb and placed in the neck.

e. The behaviour of bone deprived of its periosteum. About this there is unanimity, and it is unfortunate that Ollier's own observations on this point should have been so much forgotten. He showed that the nude bone lived, grew in length and thickness, formed callus, and healed after fracture (obs. 14–17); also, that if the periosteum were removed, the bone beneath quickly re-formed a new periosteum, which had the same osteogenetic properties as the original (obs. 11–13).

f. The microscopic appearances after bone grafting. Axhausen has without doubt shown that after bone grafting the chief osteogenesis in the graft occurs beneath the periosteum. But it might equally well be stated that the new bone is formed from the superficial surface of the old bone as that it arises from the deep surface of the periosteum. It is exactly the old fallacy of crediting all superficial callus to the periosteum, when in reality it comes from the bone, as is proved by the fact that it is produced just as well if the periosteum has been removed. This point is so important that I here interpolate a preparation of my own, taken from a fractured cat's tibia after seventeen days (***Fig.* 130**). It shows an exuberant layer of superficial callus lying between the dense bone and the periosteum. In the process of cutting the section the soft callus has become detached from the hard bone, and remains attached to the periosteum, exactly in the same way as the inflammatory callus of an osteomyelitis, exuded from the bone, is split from it to form the involucrum. Nothing but the most superficial observation, however, could suggest that the callus in this specimen has come from the periosteum. It contains two well-marked stages, viz., the early cartilage and the late bone, and the former is becoming converted into the latter. But the bone callus is next to the bone, whilst the cartilage callus is next to the periosteum, showing that the original site of origin of the whole was from the bone, and that it was formed from within outwards, and not in the reverse direction.

It is unfortunate that the term 'periosteal' may equally well mean 'derived from the periosteum,' or simply indicate a position upon the outer surface of the bone. If throughout Axhausen's descriptions the term 'layer superficial to the bone' were substituted for the term 'periosteal,' it would be

equally accurate, and would be much fairer, as being free from the unproved assumption that the layer in question was derived from the membrane above it and not from the bone beneath it. In order to avoid this difficulty, and to escape from the use of the above phrase, I would suggest the use of the term

FIG. 130.—Cat's tibia, 17 days after operation. Longitudinal section of the dense bone, with the overlying external callus, as seen under a ⅓-in. objective.

B, Dense bone of the shaft. S, Space between the callus and the dense bone, artificially produced in the cutting of the section. O.C, Deep layer of ossified callus. C.C, Outer layer of cartilaginous callus. P, Periosteum fused with overlying connective tissue.

There can be no doubt that this thick layer of external callus is growing in direct continuity with the bone, and the ossification proceeding from the bone. The way in which the callus breaks from the bone in the process of cutting the section, although purely accidental, is nevertheless very instructive, because it marks the line of most ready cleavage, between two layers of tissue of different density. When necrosis occurs, it is in this line of cleavage that the inflammatory products accumulate and separate the outer involucrum from the inner sequestrum. But, nevertheless, the involucrum has grown from the bone.

'epiosteal' to denote the structures on the surface of the bone beneath the periosteum. Axhausen proves the importance of the epiosteal bone layer, but he does not prove its origin from the periosteum.

g. The periosteum as a limiting membrane. All are agreed that the

periosteum is the bounding wall of bone, but it is also in some senses a limiting membrane, i.e., it limits and to some extent hinders bone growth. Macewen proves this (obs. 23, 24) by demonstrating the unrestrained exuberant growth which sometimes takes place after removal of the periosteum and a portion of the bone. This growth sometimes penetrated into the muscle layers surrounding the injured bone.

Axhausen's observations (obs. 9) confirm this in a different way. The epiosteal new bone formation was observed to be much more marked at the cut ends of the graft, and where the periosteum had been incised, than where the membrane was intact. At these points the epiosteum is relieved from the limiting action of the periosteum, and the bone-cells can be freely poured out, and grow.

h. The periosteum as a nutritive vascular membrane. There is no dispute about the fact that the bone receives its blood-supply partly through the vessels of the periosteum, and that when a part of the bone is separated from the rest, this constitutes for a time its sole blood-supply. Further, the surface of the periosteum readily becomes adherent to adjacent vascular structures, and becomes vascularized by them, in bone grafting; whereas a piece of nude bone offers the greatest possible resistance to the formation of new vessels, a process which cannot take place until it has been honeycombed by lacunar absorption.

Axhausen proved that grafts taken with their periosteum show a much greater viability and osteogenesis than nude grafts, and although he does not himself point out the possibility that this is due to the more ready vascularization, yet he relates facts which are very suggestive of this. Thus, he points out (obs. 8) that viability of the periosteum depends upon its coming into direct contact with vascular living tissues, and that if blood-effusion or adherent muscle intervenes between the periosteum and its bed, the former will die. He admits (obs. 5) that in some areas of even the dense bone of a graft, superficial portions show cells remaining alive, and this is just at points where the overlying periosteum has retained its vitality.

McWilliams (*vide infra*) has especially called attention to the importance of the periosteum on a graft in affording a ready means of establishing a new vascular connection with its bed.

Summary.—The periosteum is chiefly a limiting membrane of the bone. The dense bone can live, grow, undergo repair, and produce fresh periosteum after the latter has been removed.

In young bones it is possible to remove the periosteum in such a way as to produce an osteogenetic membrane, this being probably due to the lifting of the epiosteum with the periosteum. In adult bones this is impossible, except after trauma or inflammation. Nevertheless, the retention of the periosteum, though not necessary, is highly desirable in grafting, because its removal takes away much of the epiosteum, and because it affords a ready means whereby the graft may become vascularized.

2. The Rôle of the Marrow Tissue.—About the marrow tissue there has never been the same difference of opinion as about the periosteum, probably because its situation and structure are such that it cannot be removed

from the bone in such a way as to take an inner layer of bone cells with it. No one has suggested that marrow tissue can be used as a free graft with osteogenetic results.

Ollier showed (obs. 10) that a tube inserted into the marrow cavity became filled with new bone; and again (obs. 16), that if the periosteum is removed and a metal foil placed round the shaft of a bone, new bone will be laid down in the marrow cavity. In other words, the deep surface of the dense bone, like the superficial, is capable of osteogenesis under suitable stimulus—there is an endosteum as well as an epiosteum. Barth figured (obs. 5) new bone formation in the marrow spaces of bone grafts. Axhausen proved (obs. 2, 10) that in living grafts new bone is formed in that layer of the marrow tissue which is next to the bone, provided that this is closely in contact with vascular tissue of the bed. This will be at the cut end only of a graft of the whole thickness of the bone, or along the whole cut surface of a split bone. Macewen does not deal separately with the behaviour of the marrow tissue, but his glass-tube experiments (obs. 20–21) are somewhat similar to that of Ollier (obs. 10) mentioned above. In both the tube became filled with new bone tissue, though in Macewen's case this was derived partly from the compact bone. Therefore we have no difficulty in saying of the red marrow tissue, that its layers next to the bone (endosteum) have precisely the same capacity for osteogenesis as the epiosteum, though in a lesser degree. If grafted in such a manner as to allow rapid vascular connection with its bed, it will take an active share in new bone formation. In other words, a split graft will be more actively proliferative than a whole graft.

3. **The Rôle of the Compact Bone.**—As regards the behaviour of the compact bone, there are no conflicting facts. Ollier proved that, quite apart from both periosteum and marrow, compact bone could live and produce new bone and undergo the callus repair of a fracture. Macewen has further established these facts beyond all controversy. Barth, however, demonstrated that the great majority of cells in the compact tissue of a graft die, and Axhausen has abundantly confirmed this observation. But this fact does not warrant the conclusion that the whole of the compact bone of a graft always dies, and is nothing but a scaffolding—for the following reasons:—

a. Axhausen's own preparations in some cases show (obs. 5) areas at the edge of the compact bone where the cells retain their vitality.

b. Quite apart from the epiosteal and endosteal layers of cells which may be regarded as originating from the compact bone, Axhausen shows (obs. 7) that the widened Haversian canals contain active osteoblasts and new bone formation, and that the surface of the compact bone of the graft becomes pitted by lacunar absorption, and that in these excavations new bone is laid down. Now it cannot be proved either in the case of the osteoblasts in the widened Haversian canals or in those of the superficial erosions, that these cells have an origin outside the bone itself. On the contrary, it is much more reasonable to suppose that they are in part derived from the osteoblasts of the graft.

c. The behaviour of a bare bone in an open fracture is very instructive in this connection. The phenomena are well known, and yet the old fallacy of

bare bone being dead is still so widely held, in spite of Macewen's teaching, that it is, I think, worth while to emphasize it by an illustrative case.

Sergt. W. had a septic gunshot fracture of the lower third of his femur. In a large wound of the outer side of the thigh, the oblique ends of the bone were easily visible, and were at first perfectly bare on both medullary and periosteal aspects. I drilled both these fragments with many holes, about an eighth of an inch in diameter, on every accessible surface. Within a very short time the bare bone pushed out buttons of granulation tissue, and these spread until almost the whole surfaces were covered. I then gave an anæsthetic, levered the two fragments into apposition, and fixed them by two wire sutures. Eventually good union occurred, the granulation tissue having been converted into callus, with the loss of a small part of one fragment thrown off as a sequestrum.

Now in such a case, at a certain period the bones exhibit just such a 'lacunar absorption' as Axhausen demonstrates in his grafts. But my contention is that it is by a proliferation of the cells of the bone itself, and not of its surroundings, that this process takes place.

d. The behaviour of bone-grafts deprived both of periosteum and endosteum. There is no divergence here about the observation that such grafts can live and also grow. But there is a difference of opinion about the explanation of this, and a difference, too, about the degree of proliferation. Axhausen admits that nude bone-grafts live and proliferate (obs. 13), but he attributes this to the adherence of episteum and endosteum. He maintains that the chance of survival and the degree of proliferation are much less in such cases than in those where the periosteum and marrow are retained. In this he is confirmed by other observers, e.g., McWilliams and Phemister. Nevertheless, his admission of the potential viability of a bit of bare bone is of cardinal importance. Macewen, on the other hand, goes to the other extreme, and maintains that fragments of bone free from periosteum or marrow have a much greater osteogenetic capacity than a piece of entire bone. His observations (obs. 14, 15, 31) are concerned both with experimental and clinical investigations. It must be conceded that he has amply demonstrated the viability and the growth of bone chips, but his evidence does not entirely bear out his contention as to the greater osteogenesis in fragments than in a whole piece of bone. This is a matter of such great practical importance that it is necessary to examine it closely, and I shall return to it later in describing my own experiments.

Let us consider these experiments on the implantation of bone chips into a bone defect. Macewen removed the periosteum from the radius of two young dogs, resected a piece of the whole thickness of the bone, divided it into small chips, and implanted these into the gap, exchanging the bone fragments of the two dogs. In both cases, after seven weeks, the gap was filled with a large mass of bone, much thicker than the original piece removed. At first sight this appears to be conclusive evidence that the bone chips have undergone very great and rapid enlargement. But Macewen himself has taught us to beware of jumping to conclusions in matters concerning the origin of new bone. In examining figures of the specimens (*Figs.* 17, 18, 19, 20 in Macewen's book), with their measurements, two striking facts arrest the attention. First, the parts of the bone on each side of the gap have undergone great

thickening, i.e., they evidently have some share in the osteogenesis. Secondly, the length of both bones experimented upon is actually shorter by a quarter of an inch and five-sixteenths of an inch than the normal bone of the opposite side, and this at once suggests that there has been loss somewhere. If the two ends have grown, and the graft between them has grown, then the total produced should surely be longer and not shorter than normal. But in Macewen's later experiments (*Figs.* 42, 43), another dog's radius is shown in which a bit had been taken out together with the periosteum, and there, too, is the same filling of the gap with a spindle-shaped thickening, *although no chips had been inserted.* The explanation is now clear. A gap in the diaphysis of a young bone is filled by the double process of epiphyseal growth and proliferation from the cut ends, and if the periosteum is absent there may occur a spindle-shaped thickening in place of the gap. If the gap is filled with bone chips the same thickness of bone is produced, but there is no evidence that the chips have anything to do with the process.

In Macewen's classical case of the boy in whom he re-formed a humerus by successive implantation of chips from other children's tibias, there is also evidence on the one hand of the survival of the grafts, with consequent stimulation of the epiphyseal cartilages to proliferation, and on the other, of the stationary behaviour of the grafted material in the matter of size. That is to say, Macewen states that on three occasions he inserted bits of bone, each making up a length of about one and a half inches. Thirty years later the skiagrams clearly show the grafted part, and this is stated to measure four and a half inches. Thus, the fragments had lived, but there was none of that exuberant proliferation which would have greatly increased their bulk.

SUMMARY.—Compact bone, if it has a proper blood-supply, is quite independent of either periosteum or endosteum for both growth and repair If deprived of its blood-supply temporarily, as in a graft, it acts in a very indolent manner: the greater part of its cells die, but those on all the free surfaces—epiosteal, endosteal, and cut edges—survive, and proliferate to form new bone. The tissue becomes vascularized, and then in the new Haversian canals new bone is deposited. Fragmentation of a graft may secure the survival of a greater number of osteoblasts, but it does not ultimately produce a larger bone.

4. **Homoplastic and Heteroplastic Grafts.**—All observers have obtained success in the transplantation of bones or parts of bones from one individual to another of the same species. Axhausen demonstrated that the viability and proliferation of a homoplastic graft were more uncertain than those of an autoplastic. Heteroplastic grafts—i.e., bones transferred from one animal to another of a different species—become encapsuled or absorbed, and show neither vitality nor proliferative capacity. They may, however, act for an indefinite period as a splint or as a scaffolding for the laying down of new bone.

A SHORT NOTICE OF SOME OTHER IMPORTANT PAPERS.

In attempting to deal with the literature of bone-grafting, one is faced with the difficulty of the vast size of the subject. McWilliams,[8] for example, has compiled references to upwards of five hundred papers. Most of these, however, merely deal with isolated observations about human grafts, and

although they amplify and add details to our knowledge, they do not modify it in any essential respect. I propose, therefore, merely to select certain papers of special importance, without attempting any general epitome, this task having recently been accomplished with conspicuous success by McWilliams.

Four American papers represent recent work suggested by Macewen's book, and they deal with experiments done on the same lines.

Davis and Hunnicutt[9] repeated and confirmed Macewen's experiments. They showed that periosteum, either as a flap or as a free graft, did not produce bone, but if a thin layer of bone was raised with this membrane, osteogenesis occurred.

Brown and Brown,[10] too, obtained results similar to Macewen They added two important observations, viz.: (1) Living bone transplanted into soft tissue only survives for a short period, and ultimately undergoes absorption. This supplements and corrects the impression left by Axhausen's work. The latter author, concentrating his attention on the early microscopical changes in free bone-grafts, demonstrated cell proliferation and osteogenesis as above described. But this is only a transitory phase, and more protracted observations show that bone-grafts in soft tissue have only a fleeting existence. (2) Similarly, bone-grafts in contact with living bones, but performing no function, undergo atrophy. Both these facts are in unison with Wolff's Law, that the size of a bone is determined by the function which it has to perform.

Phemister[11] has published one of the most complete and carefully described series of experiments on this subject ever recorded. He removed about a third of the ulna in dogs, and replaced the graft into its bed under different conditions. These experiments demonstrated:

1. Actual osteogenesis occurring in the graft.
2. Osteogenesis occurring in a graft deprived both of its periosteum and endosteum. This was, however, much more scanty than that occurring in whole or split grafts.
3. The most marked osteogenesis always occurs in the region of the epiosteum and endosteum.
4. Of fragmented grafts many pieces die, but slow and scanty osteogenesis does occur round most of the separate pieces.
5. A fractured graft shows osteogenesis, i.e., callus formation, at the seat of fracture, and this is even more marked than the osteogenesis occurring between the ends of the graft and the mother bone.
6. Free periosteum does not produce bone.
7. Bone transplanted into soft tissues atrophies.
8. In a periosteal sleeve from which bone has been removed, then boiled and replaced, a cylinder of callus makes its appearance on the deep surface of the periosteum.

McWilliams[12] has recorded both human and animal results. In the former, several cases are noted in which a nude graft lived for a time and then became absorbed. One case is especially instructive—a fractured tibia in a child in which a nude graft failed (this was very small, and had poor contact with the bone ends). Afterwards a piece of the fibula was used with its periosteum. This was much larger, and had much better contact with the bones than in the case of the former graft. The fibula graft lived well, and grew in

thickness. It became fractured and underwent normal callus union. This osteogenetic callus formation in a fractured graft has often been observed, and recorded by Phemister, Robert Jones, and Küttner, among others, and it forms a convincing proof of the osteogenetic properties of a bone-graft.

McWilliams' experimental results demonstrated the practical importance of the periosteum. They showed that although nude grafts could live, yet they did so in a much smaller proportion than those transplanted with the periosteum. Split grafts also did better than whole ones. These observations confirm the importance of securing a ready blood-supply to the epiosteum and endosteum.

Läwen[13] gives a very detailed account of a human autoplastic graft, with some beautiful microscopical preparations. A boy, age 8, had the upper part of the humerus resected for a myeloma, and a piece of his tibia, covered on one side by periosteum, was substituted. Seventy-eight days later, amputation was performed for recurrence of the tumour. The specimen showed all the details described by Axhausen in his experimental work. The graft was richly vascular, but the bone-cells in the compact tissue had disappeared. Epiosteal and endosteal new bone was well marked, and there was extensive lacunar absorption of the dead bone, and new bone formation round the new vessels.

On the Grafting of Homoplastic Joint-ends.—Axhausen[14] has added to the work already described an important series of new experiments dealing with the transplantation of joint-ends of bones. Working with young rats and rabbits, he obtained functionally successful results. Bone tissue behaved similarly to that in his other experiments. The articular cartilage, after an initial stage of indolence, showed the superficial cells with good vitality, and the deep cells undergoing necrosis. Eventually the latter became substituted by the former, and the tissue as a whole remained active and vital. The epiphyseal cartilage mostly necrosed, only the superficial part remaining alive. The surviving part soon became ossified, and the rest underwent lacunar absorption.

Lexer[15] has had remarkable success in transplanting half or whole joints in the human subject. In a man with a myeloid growth of the upper end of the tibia, the head of the bone was removed, and substituted by a corresponding part of the bone from a recently amputated leg. Perfect functional success followed, but the limb had to be amputated eighteen months later on account of neurosis. But Lexer's classical case was that of a girl, age 18, in whom he resected the tuberculous knee-joint and replaced it by the joint from a recent amputation. The case was shown at the German Surgical Congress, and nearly two years later the patient could walk well with a stick, and had free movement in the joint.

He makes the following general observations as the result of his work. The joint should be exposed by a broad flap incision so as to avoid a suture line over the graft. Accurate hæmostasis is essential, as any blood collection will prevent union of the graft with its surroundings; and it is better to avoid the use of a tourniquet because of the liability to subsequent oozing. It is of great importance that the bone ends should fit accurately, but he avoids the use of any foreign body for the purpose of fixation. If such is necessary, he uses fresh autogenous bone pegs. Joints taken from freshly amputated limbs, or

those from corpses taken within twenty-four hours of death, may be used. All tendons, muscle, fat, and ligaments must be removed from the graft, and the periosteum divided by longitudinal incisions. He is uncertain whether the best success will be given by retention or removal of the synovial membrane, the evidence on this point being conflicting. If an important muscle-tendon group has been destroyed, e.g., that of the quadriceps and patella over the knee, it is best to wait until the main graft has healed, and then to do a new tendon-grafting. The later history of joint transplantation shows a stage of grating like that of rheumatoid arthritis, but movement is free and painless, and the grating becomes less with use.

Küttner,[16] too, has had great success with homoplastic transplantation of joint-ends in two instances. Particulars of his cases are added.

Case 1.—Patient had the upper end of the femur removed for sarcoma, and a bone taken from a corpse, thirty-five hours after death, was used to replace the lost portion. He had excellent use of the leg, but died thirteen months later of metastatic growths. To the naked eye the specimen showed neither necrosis nor absorption. Sound callus union had occurred between the graft and its bed. It was very remarkable how firmly the muscles had acquired a normal attachment to the graft. Microscopical facts revealed were: the survival of the articular cartilage, the absence of cells from the compact bone, and the presence of an epiosteal layer of new bone and of some lacunar substitution at the point of junction with the main bone.

Case 2.—The upper third of the femur was removed for sarcoma, and a graft was taken from a corpse, three hours after death. It was adjusted with the help of an intramedullary fibular graft, also taken from the corpse. Later on a fracture of the graft occurred, and this healed by natural callus. Finally, amputation had to be done on account of recurrence. Examination showed the same points as in *Case* 1, viz., firm attachment of muscle to the graft, retained articular cartilage, loss of the cells in the compact tissue, and early substitution by the surrounding tissues.

Case 3.—A child with congenital absence of the fibula had a fibula grafted from the leg of a Java ape. This remained *in situ* for nearly two years, but the *x*-ray picture gives no suggestion of any growth or function.

On the Use of Dead bone-grafts.—The use of sterilized bone or ivory for filling bone defects has often been employed, and although since the knowledge of the possibilities of living grafts it has fallen into the background, yet it is a subject of practical importance which we cannot afford to ignore. For the present purpose it will be sufficient to refer to König's work as illustrative of this branch of the subject.

König[17] has used ivory intramedullary pegs and periosteal ivory plates for the operative treatment of fractures. Encouraged by the results of these cases, he had ivory models made of various parts of the bones, and these he has used several times to replace parts lost by injury or disease—e.g., half the lower end of the humerus in one case, and two cases of half the lower jaw. In all of these smooth healing occurred in the first place, but in several a purulent sinus developed after several months or years, necessitating the removal of the foreign body. His most remarkable case was that of a woman, age 62, in whom the half mandible was replaced by an ivory prothesis. It not only healed quite smoothly, but became firmly attached to the remaining half of the jaw, whilst articulating freely in the temporal joint. She was shown at the

German Surgical Congress, and at the time of the report, two years after the operation, the result appeared to be perfectly satisfactory.

If an ivory peg heals with perfect asepsis, it quickly becomes pitted and roughened by ingrowth of surrounding granulation tissue. By this means it is incorporated with the structures of its bed. If, on the other hand, sepsis occurs, the graft may remain in position for an indefinite period, but it never is really attached to its surroundings, and when removed its surface is perfectly smooth.

Barth's work has familiarized us with the idea that dead bone and ivory may, under favourable circumstances, heal with the tissues and become incorporated by them, being substituted by connective tissue, or by bone if osseous tissue is ready at hand.

It may be demonstrated by the *x* rays that ivory pegs become completely absorbed in a period of one to ten years. Stieda[18] gives a good illustration of this. A girl, age ten, with a congenital fracture of the tibia, with pseudo-arthrosis, had had several operations without success. Then two stout pieces of boiled tibia from an amputated limb were fixed round the fractured area, and consolidation occurred. Eleven years later the bone was thick and firm, and not the slightest trace of the bone-plates can be seen in the skiagram.

The question then arises whether it is reasonable or consistent to imagine that dead-bone pegs will become absorbed under one set of circumstances, and yet remain indefinitely as a permanent skeletal structure in another. It is unfortunate that König gives no *x*-ray pictures of his cases to clear up this point. In his best case only two years had elapsed since the massive piece of ivory had been inserted. It is quite possible that small pieces of dead bone may become absorbed, whilst large ones remain. In the latter case, a certain depth of the outer part of the graft will be eaten into and substituted by connective tissue, whilst the central mass will remain. The same thing is seen in connection with the absorption of dead bone resulting from sepsis. Small particles are eroded and eaten up by granulation tissue, but large pieces will remain as sequestra for an indefinite period.

Albee's work[19] has been almost entirely of a practical character. By a great improvement in operative technique, he has placed the subject of bone-grafting upon the footing of a regular surgical procedure, the indications for which appear to be more frequent every day. His pioneer work lay in the introduction of a method of bone-grafting for Pott's disease of the spine. He split the spinous processes of several vertebræ above, below, and including the affected area, and then sewed in a piece of the inner surface of the shaft of the tibia. The cases in which this operation has been done are now several hundreds, and the results are said to be very satisfactory. But his precise method of laying in bone-grafts in order to unite fractures and to make good defects in the long bones constitute the most valuable part of his work. Inasmuch as the novelty of Albee's work chiefly relates to matters of technique, and not to the principles of bone-grafting, it will be more convenient to postpone a critical examination of it until a later part of the present paper.

Lindemann[20] has recently published a long series of cases of bone-grafting for fractured jaws; this deserves special mention, because of the importance

of this branch of the subject, and because there are so few publications which deal with more than one or two isolated cases.

In the first place, he attaches cardinal importance to a proper immobilization of the jaw by suitable splints, and to a proper closure of any defect in the soft parts, by a plastic operation if necessary. Any sepsis evident before the operation, or discovered during its early stages, should lead to the postponement of the bone-grafting. The jaw is exposed by an external incision, and on no account must the oral cavity be opened. The ends of the jaw fragments are exposed, and bared of connective tissue. Then an opening is made into the marrow cavity of each. Next a piece of the inner surface of the tibia is taken of suitable length, and its ends are fashioned into peg-shaped processes to fit into the holes of the jaw fragments. In this manner Lindemann has implanted grafts varying in length from 1½ up to 13 cm. In the great majority the graft measured 2½ cm. He recounts 97 cases; primary union occurred in 86, and 51 of these obtained firm bone union, whilst in many others consolidation was in progress.

The Cultivation of Bone-tissue in Vitro.—One other aspect of the question of bone-grafting requires mention. Living bone tissue can be cultivated *in vitro*, and the resulting phenomena have an important bearing on the problem of the survival of grafts and on the rôle of the different tissues.

Dobrowolskaja[21] has carried out this work. Small pieces of bone were taken from young animals (mice, kittens, rabbits), placed on slides in homogenous plasma, and covered with a watch-glass with a hanging drop of distilled water, the cell being hermetically sealed with paraffin. The preparation was placed in the incubator. When whole pieces of bone were used with periosteum and marrow attached, such a luxuriant cell growth occurred, accompanied by intense round-cell infiltration, as to obscure details of the growth. When small pieces of bone were cultivated without either periosteum or marrow, a definite and clear growth of bone-cells occurred, free from round-celled infiltration. Different forms of cells were seen, with processes growing out from the compact bone. Sometimes, if two pieces of bone were close to one another, the space between them was rapidly filled by growing cells, which united the two parts. Cultivation of periosteum, on the other hand, even in young animals, produced hardly any growth. Pieces of spongy bone containing marrow tissue gave rise to an active growth in which round-celled infiltration predominated.

On the Use of Pedicled Bone-grafts.—Until recent years, the possibility of free transplantation of bone was not generally recognized, and when a bone-graft was performed, a flap of skin and connective tissue was raised with an underlying piece of bone, and sewn into the defect. In this way an adequate blood-supply to the bone-graft was secured, and many brilliant results were achieved.

The most frequently performed of these operations have been as follows: (1) Formation of a new nose: by taking a forehead flap containing a part of the frontal bone, or a flap from the forearm containing a piece of the ulna, or a finger with its phalanx, and other still more complicated processes. (2) Filling defects in the lower jaw: by taking a chest flap containing a section of the clavicle or a rib, or a flap from an adjacent part of the face with a bit of the underlying jaw-bone. (3) Gaps in the tibia have often been made good by a flap from the opposite shin containing a part of the crest of the tibia;

in some cases a flap from the same leg containing a piece of the fibula has been used with success. (4) Gaps in the humerus : filled by a chest flap with a bit of rib, or a flap from the shoulder containing the spine of the scapula. (5) Gaps in the femur : filled by a flap from the same thigh containing a piece of the femur, or a flap from the buttock with the crest of the ilium. For details regarding the technique of these operations and the authorities who have used them, I would refer the reader to McWilliams' " Collective Review."

In general terms it may be said that these elaborate pedicle operations are almost obsolete. They all involve very grave disadvantages : the operation itself is usually one of considerable difficulty ; it often necessitates several operations ; it leaves a large gap in the part from which the flap is taken to be filled in by further plastic procedure ; and, most important of all, it is a type of operation which temporarily leaves open the tissues, and therefore asepsis is impossible. There are two possible advantages to be placed against all these drawbacks. A well-nourished flap with a good pedicle can be implanted in a granulating surface with better prospects of healing than will be afforded by a free graft. Secondly, such a flap will serve to fill up a gap left in the soft tissues as well as the defect in the bone. Probably, however, it is better to deal with the soft tissues and the bone separately, first making good the former by a suitable plastic operation, and then, when sound healing has occurred, implanting a free bone-graft.

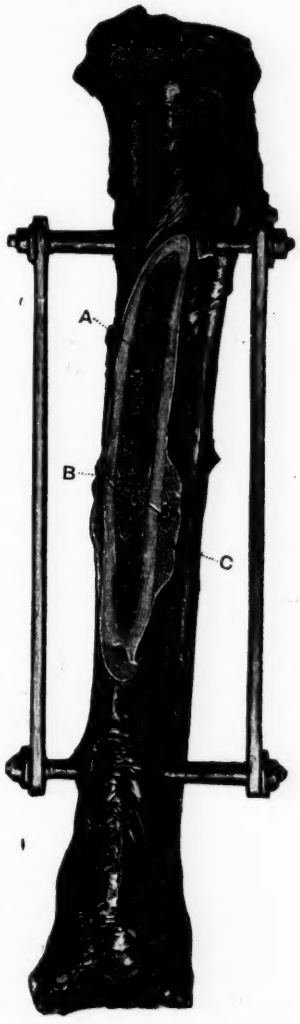

FIG. 131.—Cat's tibia, 14 days after fracture, with double-transfixion apparatus. A, Islet of cartilage present in the medulla far from the fracture. B Internal callus, present only in the upper fragment. C. External callus.

II. ORIGINAL EXPERIMENTAL OBSERVATIONS.

A consideration of the work already done on the subject of bone-grafting has convinced me that, so far as the biological aspect is concerned, the main facts, as already set out, are well established. My own experiments, therefore, have been directed chiefly to a determination of practical conclusions having a direct bearing upon the best methods of transplanting bone-tissue so as to make good defects left by trauma or disease.

The experiments have been performed on adult cats, using chiefly the tibia and the femur. In order to overcome the difficulty of immobilization of the limb, I have used, when necessary, a double-transfixion splint for the tibia. This consists of two rods which transfix the bone at its upper and lower ends, the extremities of the rods being fixed by screw-nuts into longitudinal steel bars which lie outside the limb on either side (*Fig.* 131). This apparatus not only serves to keep the bones

in place, but it also secures the dressing so that the animal cannot lick its wound during the early stages of healing.

A bone defect, however caused, may be made good in various ways, as shown in the following scheme.

SOURCES OF GRAFT.—

Living.—From the same individual—autogenous.
From another individual of the same species—homogenous.
From an animal of another species—heterogenous.

Dead.—Sterilized bone or ivory.

STRUCTURE OF LIVING GRAFTS.—

With periosteum and marrow—entire.
Without periosteum, with marrow.
Without periosteum or marrow—nude.
Coarsely fragmented.
Reduced to dust.

MANNER OF THE FIXATION OF THE GRAFT.—

A graft of the whole thickness of the bone placed end to end in apposition with the fragments of the bed.
A graft of the half thickness of the bone mortised to its bed.
Suture: (*a*) Not employed; (*b*) Of absorbable material. e.g., catgut; (*c*) Of non-absorbable material, e.g., wire; (*d*) By bolts and screws, etc.

From a practical point of view, the relative advantages of these different methods of grafting have to some extent already been settled.

Thus, the following may be taken as already proved :—

1. Living grafts are better than dead.
2. Autogenous grafts are better than homogenous.
3. Homogenous grafts are better than heterogenous.

The following propositions are based upon sufficient weight of evidence to cause them to be generally adopted as rules of practice :—

1. A graft provided with periosteum and endosteum will more surely live and more quickly grow than a nude graft.
2. In conditions where a bone defect cannot be replaced by an autogenous graft, i.e., a complicated articular surface, the use of a homogenous graft taken from a recent amputation or a corpse is indicated.

The following are questions to which there are no uniformly accepted answers founded upon definite evidence :—

1. If a graft can be secured of the full thickness of the bone which has to be mended, is it better to use the whole of the graft or to split it ?
2. If a graft cannot be provided of the same bulk as the bone it has to replace, will it be better to use the graft as a single piece or to break it up into fragments ?
3. Can living bone be reduced to dust in such a way as to form a living plastic material ?

4. Supposing that enough living bone can be secured to use either method, does cortical or medullary grafting give the better result ?
5. In relation to the bone contact of the graft with its bed, are (*a*) The extent of the contact ; (*b*) Accuracy of apposition matters of importance ?
6. Ought a graft to be firmly fixed to its bed, or is temporary suture by animal membrane sufficient ?
7. What is the effect of metal sutures, e.g., wires, screws, or bolts, upon the grafting process ?
8. Has living bone any advantage over dead for grafts of a temporary purpose, e.g., pegs ?
9. Is absolute prolonged immobilization of the limb necessary in bone-grafting ; or, if not necessary, is it beneficial ?

The following series of experiments is a contribution to the evidence necessary for answering the questions involved in the last nine propositions.

A.—Cortical Grafts.

Experiment 1 (*Fig.* 132).—**Grafting the Whole Thickness of a Portion of Bone.**—From an adult cat a piece of the left tibia was removed subperiosteally, and then replaced, merely reversing the ends so that the proximal end of the graft lay against the distal end of the bone, and vice versa. The limb was immobilized by transfixion. Healing was primary, and the animal was killed in six weeks.

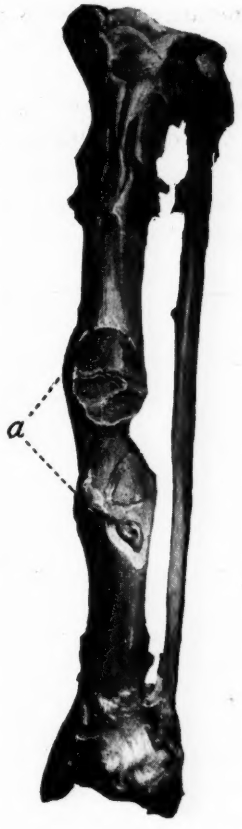

Fig. 132. — *Experiment* 1. Cat's tibia after a portion has been removed and replaced as a graft. *a*, Graft. At both points of junction of the graft with the bone, a superficial portion has been cut away to show the line of union.

The specimen shows firm and accurate bony union between the graft and its bed at each end. There is marked thickening of the graft at each extremity. That this is not merely due to a deposit of new periosteal bone, or to a growth over the graft from its bed, is shown by the fact that the graft is altered interstitially so as to present an open spongy texture. The central portion of the graft represents the original thickness of the bone, and it will be seen that both ends of the original shaft have become thickened for some distance from the lines of union with the graft.

This experiment shows how well a whole-thickness graft grows into place, and how quickly and perfectly it will be able to functionate. No suturing is required to fix it, because with proper splinting there is no tendency to displacement. The layers of the graft are firmly in contact with the corresponding layers of the bed, and there is perfect mechanical stability, without the necessity for the filling up of gaps or the absorption of unnecessary

structures. In fact, when such a graft is in place, we have practically a double fracture of the bone in perfect position, without loss either of form or substance.

It is evident, however, that this ideal type of autogenous graft can seldom be employed clinically, because it is impossible to get a graft from the patient of the same size and shape as the lost part. The use of a portion of the shaft of the fibula for a defect in the forearm bones is the only clinical instance where this method can be followed. It is therefore necessary to turn our attention to methods of using grafts from a portion of the thickness of the bone.

Experiments 2, 3, 4.—**Cortical Grafting of a Portion of the Thickness of the Shaft, there being a Fracture but no Gap in the Bone to be Mended.**—A piece of the front of the tibia about one inch long was cut out, taking a little less than one-half of the thickness of the bone. The rest of the shaft was now divided at about the middle of the area from which this part had been taken. The graft was then reapplied, reversing the ends, so that it should not exactly lie in its original position. It was fixed by four wire sutures, placed in the manner indicated in the diagram (*Fig.* 133). No transfixion or any restrictive apparatus was used.

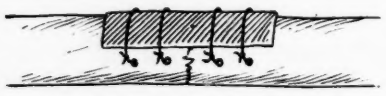

FIG. 133.—Diagram of graft fixed by four wire sutures passing through the bone ends.

In all these experiments primary smooth healing occurred, and *Figs.* 134, 135, 136 represent the results after four, six, and eight weeks. It will not be necessary to describe each of these in detail, as the main features are the same. The alinement has been perfectly maintained, and union is just like that in a subperiosteal comminuted fracture. In *Experiment* 2 (*Fig.* 134) the graft has fully united to its bed at one end only. In *Experiments* 3 and 4 (*Figs.* 135, 136) the union is complete, whilst in the former (*Fig.* 135) the thickening undergone by the graft itself is very manifest.

In these experiments the graft acted as an immobilizing splint, and there was no external fixation, nor any restriction of the animal's movements. Metal sutures, however, were employed which firmly attached the bone to the graft, and these served to secure immobility. There is no evidence that these metal sutures exercised any inhibitory influence upon the process of repair.

This method of grafting half the thickness of the bone as a cortical graft, then, gives ideal results. It represents a method of treating fractures by the use of a living-bone graft instead of a metal plate, and if the graft is sufficiently stout, and is properly fixed, it will give good results with much greater certainty, because the graft rapidly becomes organically united to the bone.

Experiments 5, 6, 7 (*Figs.* 137, 138, 139, 140, 141)—**Cortical Graft of Half the Thickness of the Shaft, there being an Actual Gap in the Bony Bed.**—Half the thickness in the front of the tibia was removed for one inch, and from the remaining part of the shaft the middle third was taken away altogether. The anterior portion was then reversed and fixed in the gap. The leg was immobilized by the double-transfixion apparatus.

In *Experiment* 5 (*Fig.* 137) the graft was fixed by wire sutures. There is perfect position, but very little macroscopical evidence of new bone formation,

either from the graft or its bed. *Fig.* 140 shows the new bone joining the graft to the bed.

In *Experiments* 6 and 7 (*Figs.* 138, 139) the graft has been fixed by split pins and washers, and in both these there is very perfect bone union between the graft and its bed.

FIG. 134.

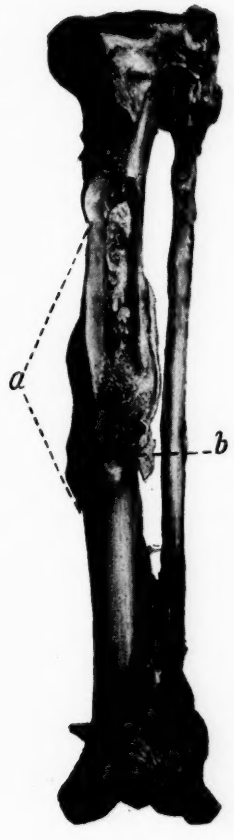

FIG. 135.

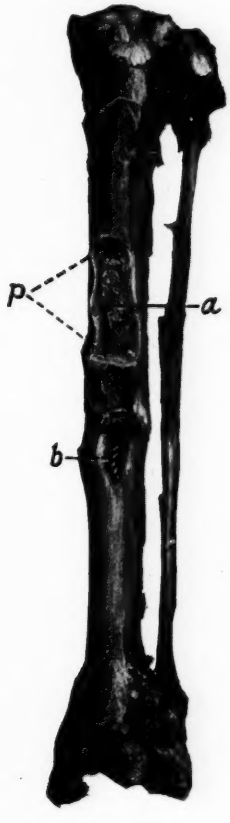

FIG. 136.

FIG. 134.—*Experiment* 2. A cortical graft of half the thickness of the tibia. After 4 weeks. *a*, Graft.

The shaft has been cut down through the middle of the graft. At the lower end bony union has occurred between the graft and its bed ; at the upper end the two are still distinct.

FIG. 135.—*Experiment* 3. Cortical graft of half the thickness of the tibia. After 6 weeks. *a*, Graft. *b*, One of the suture wires almost buried.

The shaft is cut down through the length of the graft. Both ends are firmly united to the bed ; the graft has increased in thickness.

FIG. 136.—*Experiment* 4. Cortical graft of half the thickness of the tibia. After 8 weeks. *p*, Piece of the shaft cut out to show the junction between the graft and its bed. *a*, Line of junction. *b*, One suture wire.

There is perfect restoration of the bone.

The conditions of these experiments represent very nearly what is commonly found after gunshot fractures with loss of bone, except that in clinical practice the graft would generally have to be taken from another bone than

that injured. Here again it may be remarked that there is no evidence of the metal sutures or pins interfering with the process of bone repair.

Fig. 140 is a microphotograph from *Experiment* 5, and *Fig.* 141 from *Experiment* 6, showing the layer of new bone between the graft and its bed, with well-marked lacunar erosion of both bones.

FIG. 137.

FIG. 138.

FIG. 139.

FIG. 137.—*Experiment* 5. A cortical graft of half the thickness of the shaft, with a gap in the remainder of the bone. After 6 weeks. *a*, Graft, which has been fixed by four wire sutures.

There is no evidence of new bone formation, except at the edges of the gap.

FIG. 138.—*Experiment* 6. Cortical graft of half the thickness of the tibia, with a gap in the shaft. *a*, Graft, fixed by split pins.

FIG. 139.—*Experiment* 7. Autogenous cortical graft, fixed by split pins. After 6 weeks. *a*, Graft.

B.—INTRAMEDULLARY GRAFTS.

The simplicity of the technique involved in the placing of a short bone peg into the marrow cavity of the fragments of a long bone from which there has been some loss of substance, has made this a very common practice in the treatment of ununited fractures.

It will be sufficient to describe and figure four experiments illustrating this procedure. In all of these a piece of the whole thickness of the left tibia was removed, and a graft was taken from the crest of the right tibia and

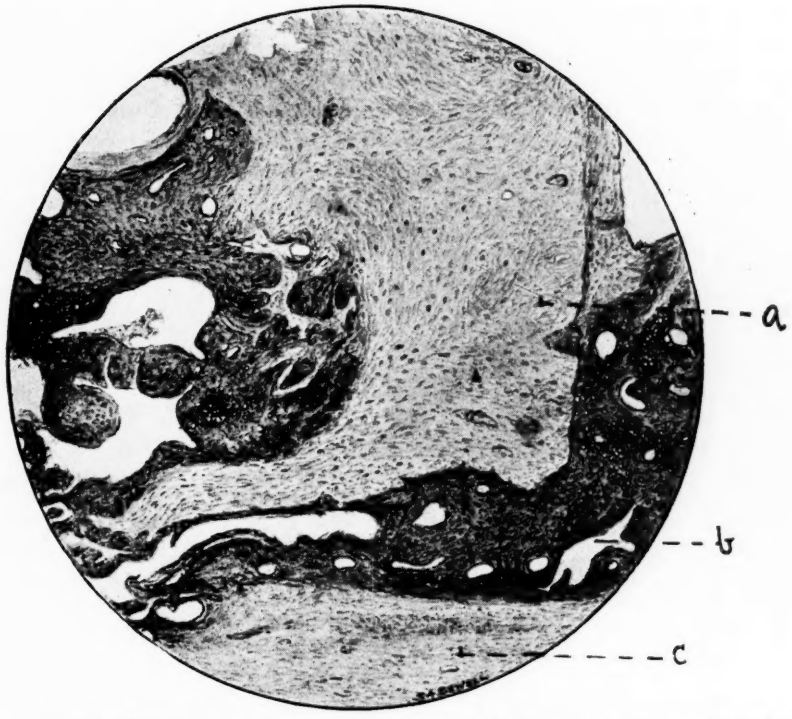

FIG. 140.—*Experiment* 5. *a*, Graft. *b*, New bone joining graft to bed. *c*, Bone bed.

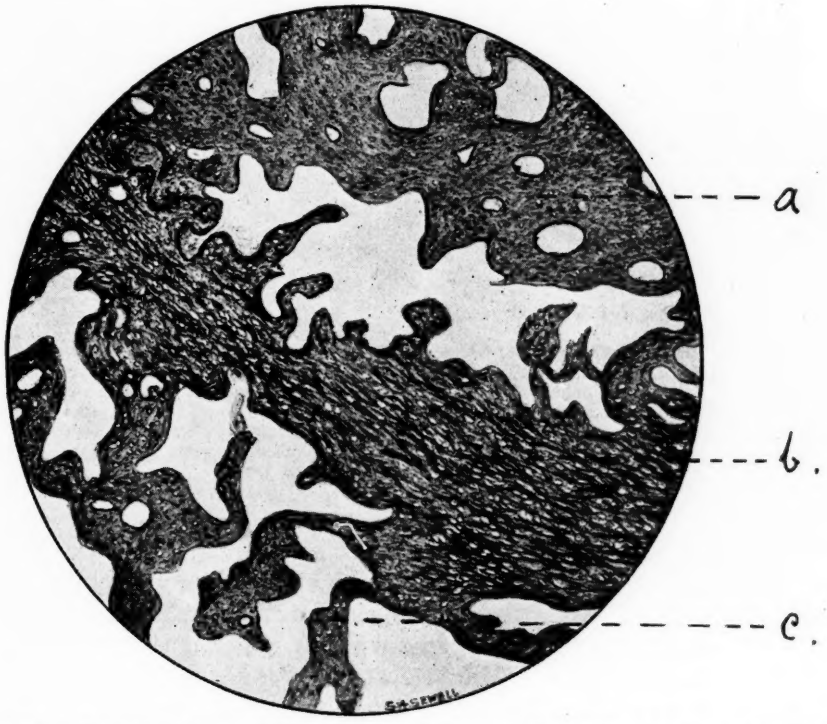

FIG. 141.—*Experiment* 6. *a*, Graft. *b*, Fibrocartilage joining graft to bed. *c* Bone bed.

employed as an intramedullary peg. The left, i.e., the divided tibia, was supported by a transfixion apparatus. All the cats were killed after six weeks.

Experiment 8 (*Fig.* 142).—In this the graft, which fitted well, had broken, and the fibula also was fractured. This latter accident must have occurred just before the animal was killed, as there is no evidence of repair. Both portions of the graft have grown firmly into the ends of the tibia, which shows scanty callus.

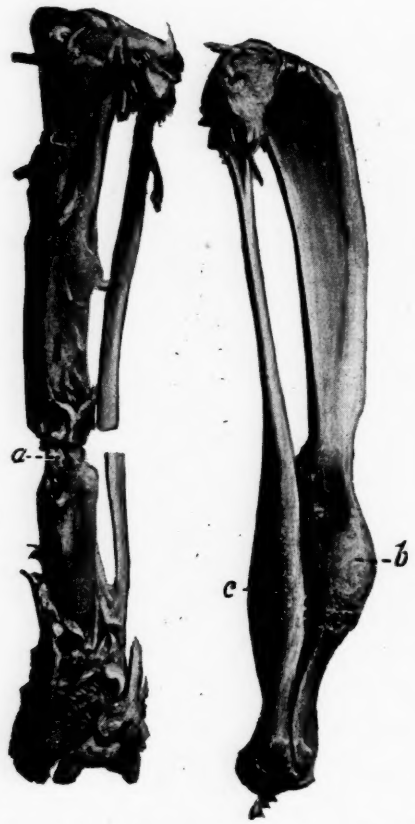

FIG. 142.—*Experiment* 8. Killed after 6 weeks.

Left side.—*a*, Intramedullary graft, broken above; firmly grown into ends of fragments, but forming very little new bone.

Right side.—The graft has been taken from the tibia. The bone has partly fractured, and undergone great callus thickening. The fibula has greatly hypertrophied. *b*, Tibial callus. *c*, Area of fibular hypertrophy.

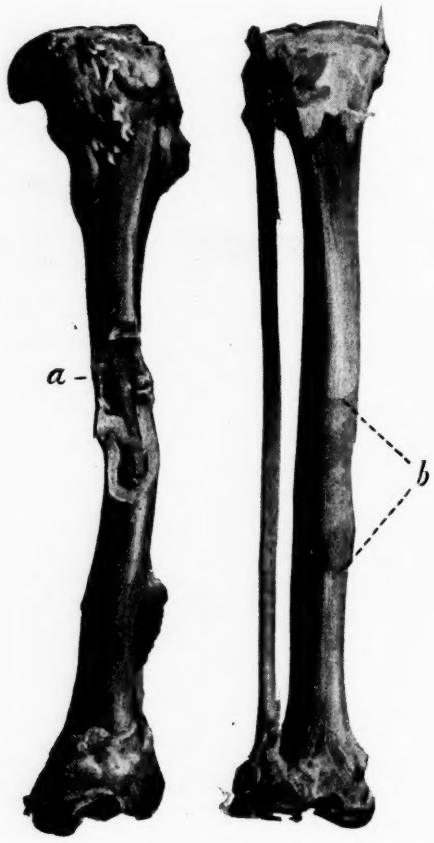

FIG. 143.—*Experiment* 9. Killed after 6 weeks.

Left tibia.—*a*, Intramedullary graft. The gap in the bone is filled by soft callus.

Right tibia.—The graft was taken from this side. *b*, The area from which a piece of bone was sawn, perfectly filled by new bone.

The right leg bones, which also are figured, demonstrate two interesting points. The tibia from which the graft was taken has undergone a partial fracture, which, being unsupported by any apparatus, has been subject to considerable mobility, with the result that a much larger mass of new bone has formed than that removed for the graft. The fibula, too, having to act as a splint to the broken tibia, has undergone a very marked hypertrophy. The

contrast between the presence of large masses of new bone on the right side and its absence on the left is a striking evidence of the influence of good blood-supply and free mobility in the promotion of osteogenesis.

Experiment 9 (*Figs.* 143, 144).—In this the medullary peg was much looser; but, on the other hand, much more callus has been thrown out by the bone ends, enough in fact to fill the gap. The peg lies in the midst of this intramedullary callus, and the microphotograph (*Fig.* 144) shows that the dense bone of the graft is opened up by lacunar absorption and the callus is insinuating itself into it. The evidence of this specimen is that the bone-graft is playing a purely passive rôle, acting neither as a splint nor as an osteogenetic

FIG. 144.—*Experiment* 9. Intramedullary graft undergoing lacunar absorption

centre. The tibia on the right side, from which the graft was taken, shows the perfect restitution which has occurred, the gap made by cutting the graft being filled up.

Experiment 9*a*.—This was performed some years ago, but the illustrative figures are here put in because they show exactly the same features as those of the last case (*Figs.* 145, 146).

Experiment 10 (*Fig.* 147).—In this the graft was made to fit tightly. It broke, however, at the point where it entered the upper fragment. The manner in which the intramedullary fragment is firmly fixed is shown by the figure. The endosteal callus is growing into the peg.

Experiment 11 (*Fig.* 148).—In this the peg was fitted as tightly as possible. It has become firmly fixed in place, but there is no new bone formed to fill the gap, and the peg has broken.

This series of experiments shows very clearly that intramedullary pegging with live grafts is of very little value as a method of inducing osteogenesis. If the graft fits tightly, it is very apt to break; and apart from this serious drawback, the tight plug in the marrow cavity of each fragment prevents the outgrowth of callus from this situation. In *Experiments* 9 and 9*a*, in which the graft lay loose in the marrow cavity, callus had been poured out in sufficient quantity to fill the bone gap, but in all the rest, where the graft acted as a plug, there was a conspicuous absence of callus repair. An intramedullary peg is a very inefficient mechanical method of bridging a bone gap. The size of the peg makes it too weak to act as a splint, and if it is fitted tightly it is snapped off by the slightest strain. The graft acts in a very passive manner, so that in no single instance could any evidence be seen of new bone growing from the graft.

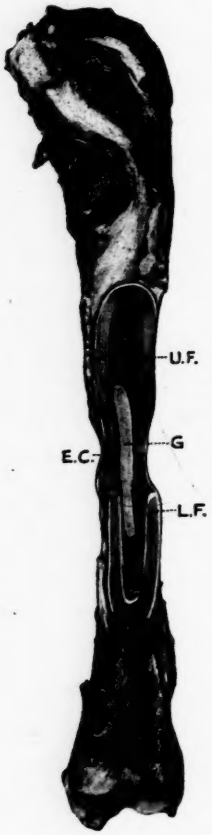

FIG. 145.

FIG. 146.

FIG. 145.—*Experiment* 9*a*. After 49 days. A graft from the opposite leg lies firmly growing into the ends of the bone and surrounded by a cartilaginous callus. U.F, Upper fragment. L.F, Lower fragment. E.C, External callus. G, Bone graft.

FIG. 146. *Experiment* 9*a*.—Skiagram of cat's tibia shown in *Fig.* 145.

FIG. 147.—*Experiment* 10. The upper part of the left tibia, with bone-graft as an intramedullary peg. *a*, The peg, which has broken below; the union was therefore a failure.

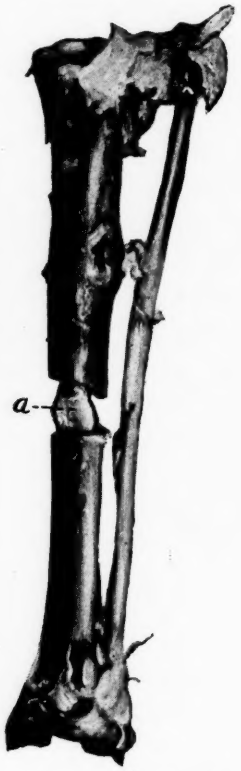

FIG. 148. — *Experiment* 11. After 6 weeks. *a*, Intramedullary bone-graft.

Firm union has occurred, but no new bone formation. The graft has fractured.

C.—The Influence of Fragmentation on the Growth of a Graft.

Experiments 12*a*, 12*b*, 12*c*.—Some years ago, when experimenting upon the methods of fracture repair, I was greatly surprised to find that if a portion of one of the long bones was removed, broken up into small pieces, and replaced,

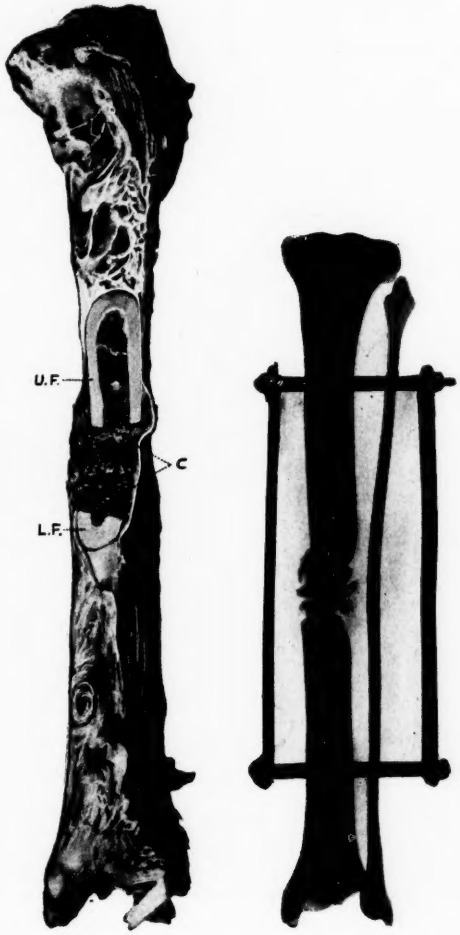

Fig. 149.

Fig. 150.

Fig. 149.—*Experiment* 12*a*. Grafting bone fragments. After 15 days. The grafted bone chips lie embedded in early callus. U.F. Upper fragment. L.F. Lower fragment. C. Callus with loose bone chips.

Fig. 150.—*Experiment* 12*a*. Skiagram of tibia illustrated in *Fig.* 149, showing separate fragments.

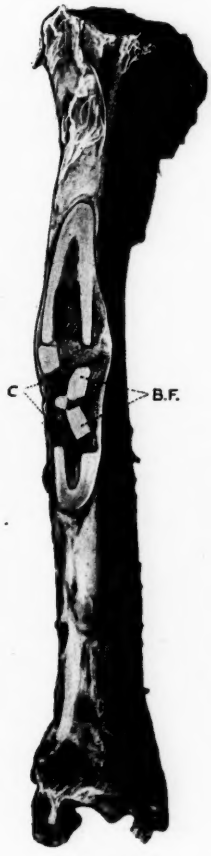

Fig. 151.

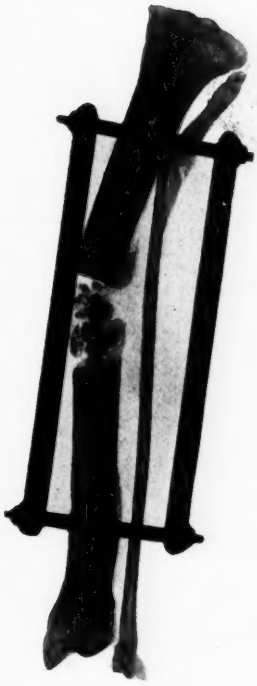

Fig. 152.

Fig. 151.—*Experiment* 12*b*. Grafting bone fragments. After 70 days. Except that the callus is cartilaginous, there is not much advance over the 15-day specimen shown in *Fig.* 149, many of the chips being still quite distinct. C, Callus. B.F, Bone fragments.

Fig. 152.—*Experiment* 12*b*. Skiagram of tibia shown in *Fig.* 151. The chips are still quite discrete.

very little new bone-formation took place. This is in great contrast to what occurs after a comminuted fracture. These experiments are illustrated in *Figs.* 149, 150, 151, 152, and 153. At the time, I thought that the phenomena must have been exceptional, because one would have expected the divided

bone to have made much new bone, each bit forming an osteogenetic centre; in fact Macewen has made this statement, and his dictum has been accepted by many. I have repeated these experiments, and give the results below.

Experiment 12 (*Fig.* 154).—A piece of the left tibia was removed and split up into as small pieces as possible by crushing, and then replaced. After six weeks the pieces of bone are still quite distinct, and not even firmly united to one another or to either main fragment.

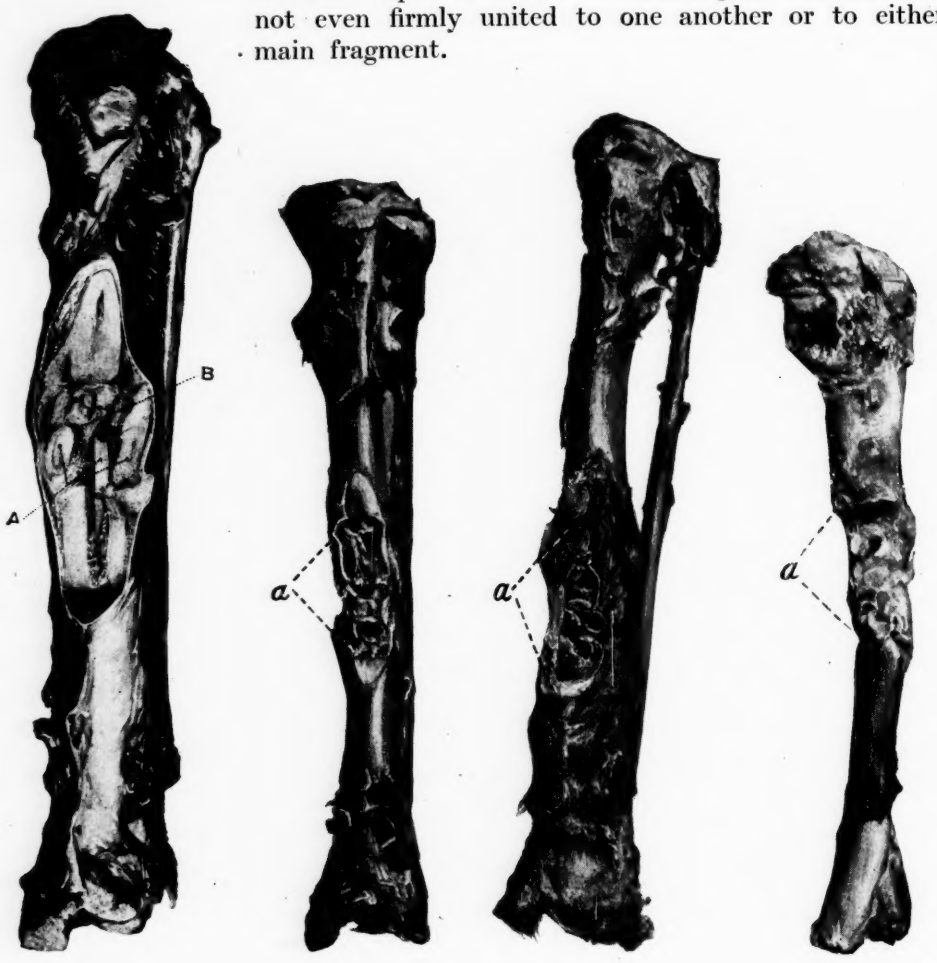

FIG. 153. FIG. 154. FIG. 155. FIG. 156.

FIG. 153.—*Experiment* 12*c*. Comminuted fracture. Fragments left *in situ*. After 8 days. A, Small fragments of bone. B, Callus growing from these fragments.
Contrast the behaviour with that of the bone chips removed and replaced shown in *Figs.* 149, 151.

FIG. 154.—*Experiment* 12. Piece removed from tibia, fragmented, and replaced. After 6 weeks. *a*, Broken-up portion.
Note the indolence of the bits of bone, and the absence of new bone growth.

FIG. 155.—*Experiment* 13. Graft broken up into small bits. *a*, Fragmented portion, exposed by a saw-cut, which has broken out some of the pieces.
The lower fragment has become inflamed, and has formed periosteal new bone, which has partly ensheathed the indolent fragments.

FIG. 156.—*Experiment* 14. After 6 weeks. *a*, Fragmented graft. No new bone.

Experiment 13 (*Fig.* 155).—The same as the last. In this specimen a definite periostitis has occurred in the lower fragment, starting at the transfixion hole. This has caused a sheath of periosteal new bone to grow up round the fragments. But otherwise the latter are just as indolent in appearance as in the last experiment. Where the specimen has been cut down to show the structure, several of the pieces have fallen out.

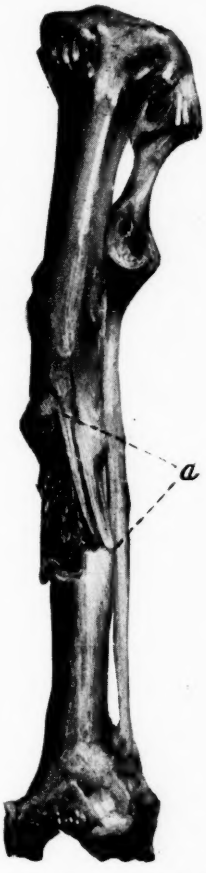

FIG. 157.—*Experiment* 15. Bone-dust grafting. After 6 weeks. *a*, Area reduced to powder.

The bone dust is replaced by connective tissue.

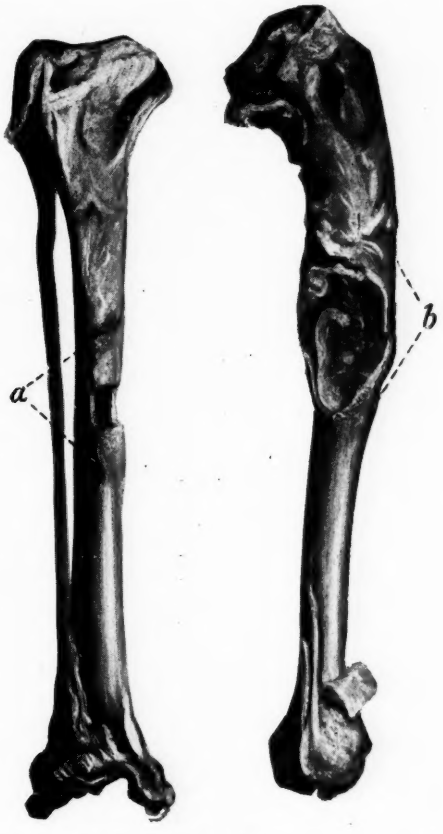

FIG. 158.—*Experiment* 16.

Right Tibia.—Half-thickness reduced to dust. *a*, Area of experiment. Re-formation of normal spongy bone.

Left Tibia.—Half-thickness fragmented. *b*, Area of experiment. Evidence of new bone.

Experiment 14 (*Fig.* 156) shows exactly the same result as *Experiment* 12. The fragments are loosely cemented together, one having fallen out when being cut, but there is no evidence of osteogenesis.

Experiment 15 (*Fig.* 157).—A piece of the whole thickness of the tibia was cut out, and reduced to powder by a small grinding machine made by a reamer working in a steel socket. The dust was replaced in its periosteal tube. After six weeks the bone dust had been completely absorbed, and replaced by blood-stained connective tissue. There is no evidence of new bone formation.

FIG. 159.—*Experiment* 16 (left tibia). Active osteogenesis is proceeding from one bone fragment.

FIG. 160.—*Experiment* 16 (right tibia). On the right is seen the compact bone of the shaft, from which is growing the new spongy bone. Only débris remains of the grafted bone dust.

Experiment 16 (*Fig.* 158).—Half the thickness was removed from both tibias for a distance of about an inch. On the left side the piece was broken up into little bits and replaced, on the right side it was reduced to powder and replaced. On the left side there was evidence of new bone formation round all the fragments, and this is borne out by microscopical examination (*Fig.* 159). On the right side, where dust was used, the tibia has re-formed to exactly its normal thickness. Microscopical examination shows that this is due to spongy callus growing from the bed of the cut shaft, and there is no trace of the dust except a little débris (*Fig.* 160).

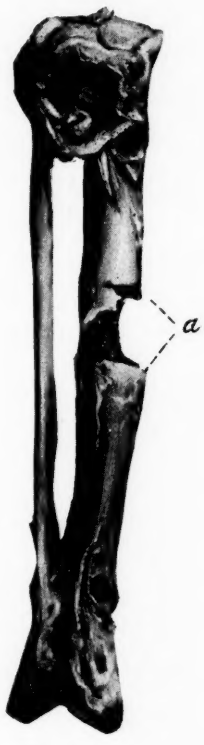

FIG. 161.

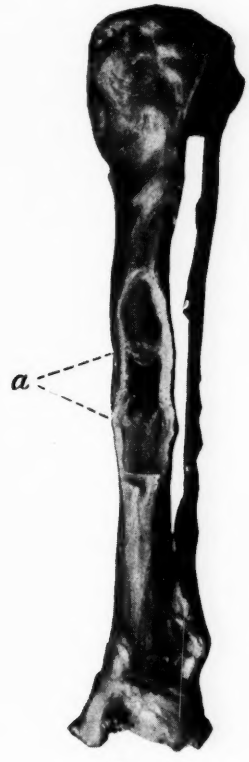

FIG. 162.

FIG. 161.—*Experiment* 17. Bone-dust graft. No new bone after 6 weeks.

FIG. 162.—*Experiment* 18. Bone-dust graft. *a*, Area of experiment. In this area there is no new bone, simply blood-stained connective tissue. A sheath of fibrocartilage has formed under the periosteum.

Experiment 17.—A piece of the tibia was removed and reduced to dust, and this was replaced in the gap. After six weeks there is nothing in the gap except blood-stained connective tissue (*Fig.* 161).

Experiment 18 (*Fig.* 162).—The same as the last. In this the gap is filled with connective tissue only, but the periosteum has formed a sheath of fibrocartilage. *Fig.* 163 shows the microscopical appearance. Callus is growing from the bone ends, and bits of the dust can be seen as débris.

This series of experiments demonstrates very conclusively that fragmentation of a living graft does nothing towards increasing its osteogenesis. In only one (*Experiment* 16) was there any evidence of an active osteogenesis occurring round the bits of bone. In this the whole thickness of the shaft had not been removed, but only half, and the pieces of bone were laid upon the raw bone and marrow surface. It is probable that, under the circumstances, the bits of bone quickly got a new blood-supply which promoted

FIG. 163.—*Experiment* 18. Spongy new bone in seen on the left, fibrocartilage on the right. (Just outside the microscopical field shown in the figure there is a fragment of bone dust, quite dead.)

their osteogenetic activity. But in all the other cases where bone chips were used to fill a gap, these acted in an extremely indolent fashion, and at the end of six weeks there was no bony union of the gap. Bone dust, too, is even more negative in its behaviour. Even when all precautions are taken, by using a coarse reamer, slowly revolving to prevent heating, the dust produced shows no osteogenetic properties. It is absorbed, and replaced by connective tissue.

D.—THE INFLUENCE OF INSECURE FIXATION.

When a bone-graft is used to fill a gap in a bone where there is no loss of continuity, it requires no suture fixation, because there is no tendency for it to be moved. But it is quite otherwise when a graft is used to bridge a gap in one

of the long bones, or to make good a defective repair of a fracture. Under these circumstances, even if external means of immobilization be most accurately applied, there is a tendency to movement between the graft and its bed which is very inimical to healing.

Experiment 19 (*Fig.* 164).—The femur of a cat was divided. From the superficial part of the shaft, above and below the fracture, a piece about half an inch long was cut out. Into the cavity a piece of the crest of the tibia was tied by two metal sutures. No other fixation. After six weeks there was

FIG. 164.

FIG. 165.

FIG. 164.—*Experiment* 19. Femur of cat, fractured, and repaired by an inlay graft of the tibia, secured by wires. After 6 weeks. *a*, Graft. *b*, Callus.
The graft has not taken at all, but there is great callus excess in the repair of the fracture.

FIG. 165.—*Experiment* 20. Fracture of tibia, with a graft from the same bone fixed by two wire sutures. After 6 weeks. *a*, Graft.
Faulty union, and no fixation of the graft.

massive callus union, but the graft was quite distinct, and had neither grown to its bed nor contributed in any way to repair, except that it had acted as a rather inefficient splint. The callus excess produced cannot be attributed to any specific stimulation of osteogenesis by the graft, because just the same growth occurs in any fracture of the lower end of the femur which is not completely immobilized.

Experiment 20 (*Fig.* 165).—The tibia of a cat was divided after a piece

one inch long had been cut from its anterior surface. This was re-applied, and fixed by two double sutures passed round the bone and the graft (*Fig.* 166). No supporting apparatus. It will be noticed that this method of fixation is very much less secure than that employed in *Experiments* 2, 3, 4. After six weeks the bone was badly united at a considerable angle. The graft was quite bare, and there was no union between it and the bed. The upper fragment had thrown out some episteal bone which had partly covered in the upper part of the graft.

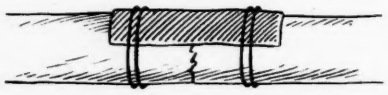

FIG. 166.—Diagram of graft fixed by two double wire sutures passed round graft and bone. Compare with *Fig.* 133.

Experiment 21 (*Fig.* 167).—A piece an inch long was removed from the front of the tibia. A gap a quarter of an inch long was made in the shaft, and the first piece was then re-applied, and fixed in place by catgut ligatures. The leg was fixed by a double-transfixion apparatus. After six weeks there was marked angulation. The upper end of the graft is united to the shaft by a firm fibrous band.

These experiments demonstrate the great importance of firm and lasting fixation of the graft to its bed. It is nothing more nor less than the necessity for firm fixation similarly observed in plant-grafting. It would hardly need demonstration or emphasis if it were not for the modern tendency to employ only absorbable ligatures. These afford no fixation in the real sense of the word after a few hours, when they become softened and yield before any strain. A comparison of the results of *Experiments* 2, 3, 4, 5, 6, and 7, in which efficient fixation by wire or pins was employed, with those where inefficient fixation by wire or suture by catgut was used, leaves no room for doubt, if such could ever seriously be entertained, that firm and lasting fixation of the graft to its bed is a factor of prime importance in all cases where continuity of the shaft of a long bone is destroyed.

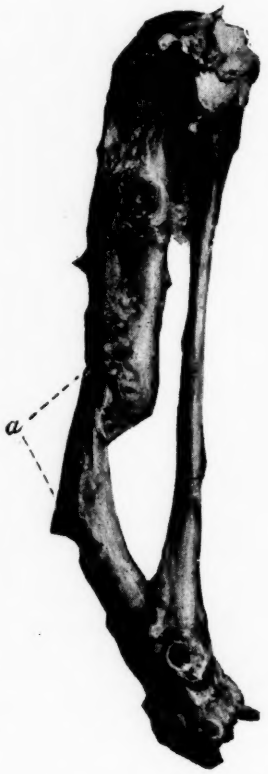

FIG. 167.—*Experiment* 21. Bone graft of the tibia used to bridge a gap. Fixation by catgut. After 6 weeks. *a*, Graft.
Faulty position, and no union between the graft and the lower fragment.

E.—THE REACTION OF LIVING BONE TO METALLIC SUTURE OR PINS.

This subject is closely related to the last. In the first place a reference may be made to *Experiments* 2, 3, 4, 5, 6, and 7, in all of which ideal healing of a grafted bone occurred after the proper use of metal sutures or of perforating split-pins. In none of these was there any sign of excessive irritation, much less of suppuration or the formation of a sinus.

If a graft be tightly bolted to a piece of living bone, as in the accompanying diagram (*Fig.* 168), there will be observed two results:

1. At the points where the metal presses upon the bone, absorption will take place until tension is relieved, exactly as in the case of a suture tied tightly in the soft tissues. But this is a vital phenomenon. It involves vascularization and cellular proliferation of the bone, and these two processes are productive of new bone formation. In the case of a graft, where at first the circulation is absent and the cells of a low vitality, it will hardly occur at all, and therefore the loosening of the grip of a metal suture upon a bone-graft will not occur unless or until the graft begins to be vascularized and to grow.

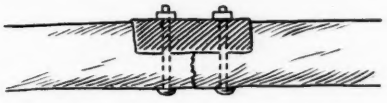

FIG. 168.—Diagram of graft fixed by bolts and nuts.

2. After a time the new bone grows round and encapsules the metal suture or pin in the manner demonstrated in *Experiments* 3 and 4. This stimulation of bone growth by metal foreign bodies is seen in a more pronounced degree in the following experiments.

FIG. 169. FIG. 170.

FIG. 169.—*Experiment* 22. Femur of a cat after a simple fracture united by a long steel plate, showing the epiosteal bone beginning to ensheathe the metal. After 6 weeks.

FIG. 170.—*Experiment* 23. Femur of a cat after a simple fracture united by a steel plate and split pins. After 8 weeks. The plate is almost buried in epiosteal new bone.

Experiment 22 (*Fig.* 169).—A simple fracture of the femur in a cat, united by a long steel plate bearing four quadrant flanges which partly encircle the shaft, and through which are passed split-pins. After six weeks there is good massive union, though the plate has been bent a little. The plate and the ends of the pins are partly buried in epiosteal new bone. Healing was by primary union, and there was no suppuration.

Experiment 23 (*Fig.* 170).—This is similar to the last, except that the plate is a strong simple plate, and the pins perforate the whole thickness of the shaft. Killed after eight weeks. The plate and pins are almost buried in new epiosteal bone. Union was primary, and there was no suppuration.

These experiments, together with the previous ones, demonstrate that properly-applied metal sutures or pins serve to keep a graft accurately applied

to its bed whilst growth is occurring between the two, and that the living bone is not prevented from osteogenesis by their presence. Eventually they become encapsuled by a covering of new bone.

F.—Homogenous and Dead-bone Grafting.

Besides the living bone-graft taken from the same individual, i.e., the autogenous graft, there are two other possible sources of bone for filling osseous defects. These are the bones taken from other individuals of the same species—homogenous grafts—and dead bone. It seems to be so well established that bones of animals of another species act simply as dead bone, that it is not worth while to examine the possibilities of heterogenous grafts as distinct from the latter.

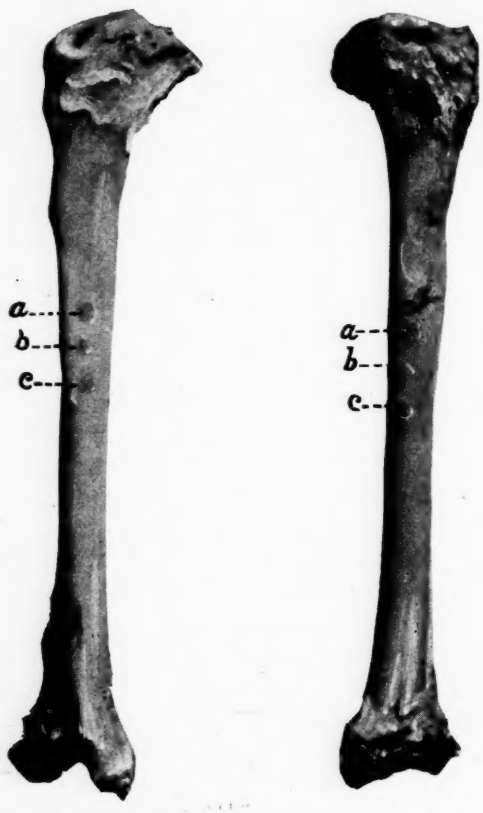

Fig. 171.—*Experiment* 24. Into both tibias of a cat three holes have been drilled. After 6 weeks. *a*, Hole filled with autogenous living bone. *b*, Homogenous living peg. *c*, Peg of boiled bone.
All have grown in place similarly.

Fig. 172.—*Experiment* 25. A graft from the fresh femur of one cat fixed into a gap in another cat's tibia. After 6 weeks. *a*, Graft.

I know of only one observation contrary to this assertion, and that is Küttner's case of the implantation of the fibula of a Java ape to make good the absence of the fibula in a congenital defect. His skiagram shows the

survival of the bone; but it has not grown, and therefore there is nothing to prove that it retained its vitality, or acted differently from a dead bone.

Experiment 24.—**Autogenous, Homogenous, and Dead-bone Pegs.**—The anterior surface of a cat's tibia was drilled by an $\frac{1}{8}$-in. drill in three places (*Fig.* 171). Into the three holes were firmly driven round pegs, formed from: (1) The same cat's tibia; (2) The femur of another cat, recently killed; and (3) The same source as the last, the peg being boiled for half an hour. Both tibias were treated in this way, the one specimen being used for microscopical examination, the other being preserved whole.

After six weeks, all three pegs have become firmly incorporated into the shaft of the bone, and no difference can be detected between any of them.

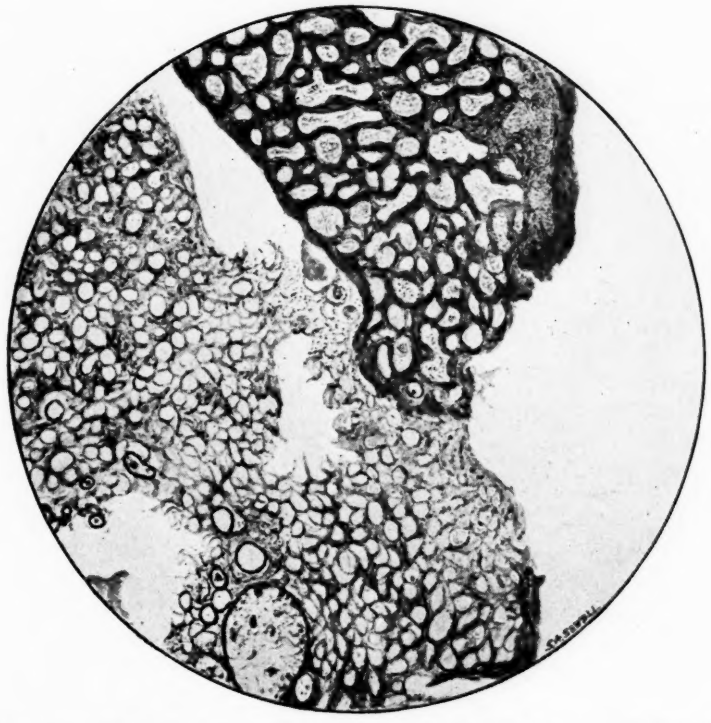

Fig. 173.—*Experiment* 25. Rarefaction at the edge of a homogenous graft.

On sawing the specimen across, all the pegs are quite fixed, and show no tendency to fall out. Microscopically, there is very little difference to be noticed. The dense bone of the shaft round the pegs is rather more open in texture than normal, owing to new blood-spaces, and rather richer in cellular contents. The tissue of none of the pegs shows any surviving cells; it exhibits some erosion at the periphery, where it is being encroached upon by the living bone.

There is a practical importance in this observation, because it shows that when used as nails, dead-bone or ivory pegs act just as well as living ones. It is obvious that it is much more practical to have bone or ivory nails prepared of the right size and shape beforehand, than to prolong any bone-grafting operation in order roughly to fashion living pegs from the patient's bone.

Homogenous Bone-grafts.

Experiment 25 (*Figs.* 172, 173).—Into a gap in a cat's tibia was fixed a piece of the femur of another cat just killed. The fixation was similar to that employed in *Experiment* 5, by wire suture and a double-transfixion apparatus. The result, as judged by macroscopical and microscopical examination, was exactly the same as when an autogenous graft was employed.

Experiment 26 (*Fig.* 174).—This was exactly similar to the last. The result was even more favourable—not only had the graft grown to the bed at the end of six weeks, but the gap made in the shaft had become evenly filled with new bone.

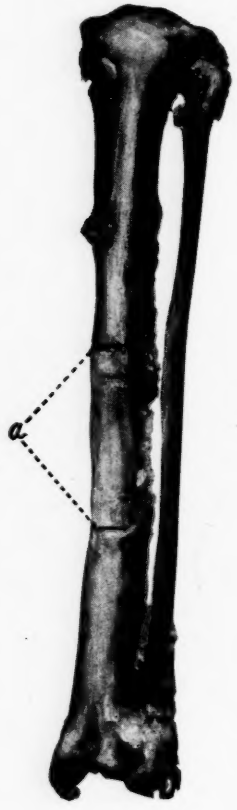

Fig. 174.

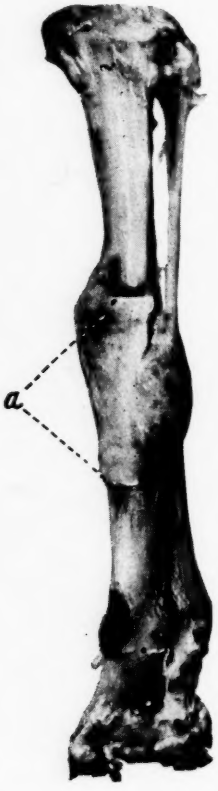

Fig. 175.

Fig. 174.—*Experiment* 26. Homogenous graft from a cat's fresh femur into another cat's tibia. After 6 weeks. *a*, Graft.

Fig. 175.—*Experiment* 27. Homogenous graft from the tibia of one cat into that of another. After 6 weeks. *a*, Graft.

Experiment 27 (*Fig.* 175).—A piece of tibia of one cat was grafted into a gap in the tibia of another cat. It was fixed by wire sutures and transfixion. After six weeks the specimen shows firm bony union between the grafts and the bed, there being, however, a little displacement, with considerable callus excess. *Fig.* 176 shows the characteristic growth of new episteal, endosteal, and Haversian new bone in the graft.

The Comparison of Dead and Living Bone-grafts in the Repair of Defects in the Long Bones.

The observation recorded in *Experiment* 24 above, showing the similar behaviour of dead and living bone when used as pegs driven into compact bone, might lead to the assumption that a dead-bone graft would serve as well as a living one for the repair of a defect in the continuity of a long bone. In order to test this, a series of experiments was performed in which only half of the thickness of the shaft of the tibia was removed, the remainder not being fractured. Both tibias were operated upon in the same animal. Into the defect on one side was placed a living graft taken from the femur of another cat, just killed. On the other side was sutured a piece from the same bone (i.e., homogenous femur) which had been boiled for a quarter of an hour. No transfixion apparatus was used :—

Experiment 28 (*Fig.* 177).—Primary union occurred on both sides.

Left Tibia: Living Graft.—After eight weeks the bone is almost exactly re-formed. Along three sides of the graft and more than half of the fourth side there is bony union between it and its bed. Only on the smaller portion of one edge is there a distinct line between the two portions of bone.

Right Tibia: Dead Graft.—After eight weeks rather a remarkable condition exists. The line of the bone has been preserved. The graft lies quite smooth and bare in a cavity which is partly surrounded by callus overgrowth from the shaft. The shaft has undergone spontaneous fracture. That this

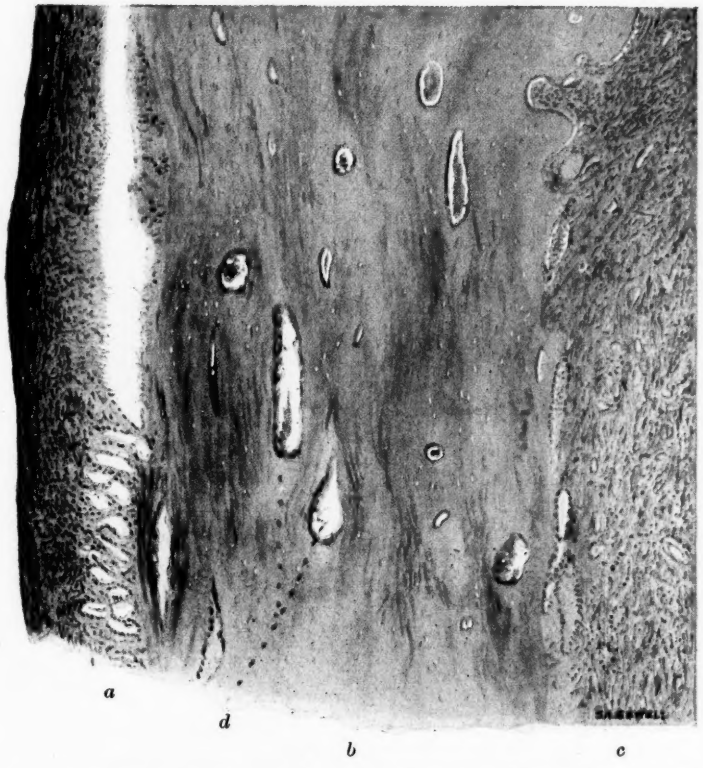

FIG 176.—*Experiment* 27. Red = graft; Blue = new bone tissue. *b*, Graft. *a*, Episteal. *c*, Endosteal. *d*, Haversian new bone formation.

is not a primary fracture, due to strain acting on the weakened bone, is shown by the fact of the bone as a whole having remained in good position whilst the callus involucrum was forming. One portion of the shaft to which the fragment was wired has undergone necrosis. The area in which the graft lay was covered by turbid fluid, and although this was encapsuled by the soft parts, and the skin was unbroken, it would probably in time have made its way to the surface and given rise to a sinus. In this specimen, therefore, not only has the graft not united, but a part of the shaft has necrosed, and actual solution of continuity of the bone has resulted.

Experiment 29 (*Fig.* 178).—The cat was killed after eight weeks.

Right Tibia: Living Graft.—Perfect bony union, the line between the graft and its bed being much obscured.

Left Tibia: Dead Graft.—Spontaneous fracture has occurred, with union in a position of much angulation, accompanied by great callus excess. The graft has, however, firmly united to the shaft of the bone above the fracture by dense bony union. Along one long side of the graft, between it and its bed, is a band of rather porous vascular bone (*Fig.* 178 x), evidently formed at the expense of the shaft, but nevertheless as firmly united to the graft as to the shaft. The huge mass of exuberant callus has been formed by the shaft below the fracture, and on one side it has almost covered in the grafted area.

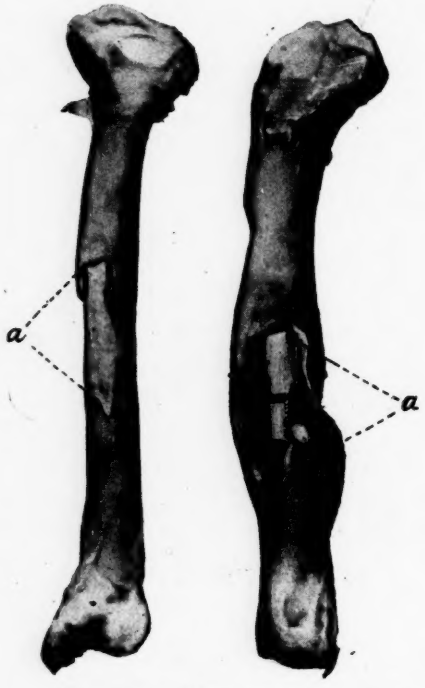

FIG. 177.—*Experiment* 28. Both tibias are from the same cat. The left-hand one has a living homogenous graft from a fresh cat's femur. The right-hand one has a boiled graft. *a*, Graft.

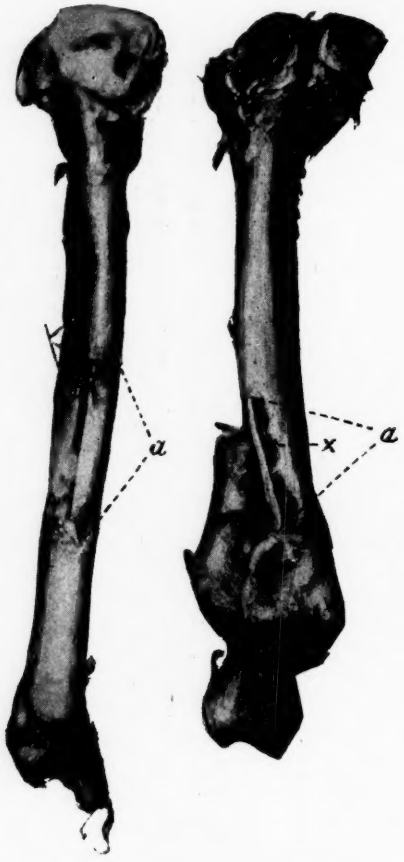

FIG. 178.—*Experiment* 29. Both tibias are from the same cat. On the left side is a living homogenous graft. On the right side is a boiled graft. *a*, Graft. x, Area of living bone which is penetrating *a*.

Experiment 30 (*Fig.* 179).—The animal was killed after eight weeks.

Right Tibia: Living Graft.—The graft has healed by firm osseous union. There is considerable overgrowth of epiosteal bone from the shaft, and this is beginning to grow up over the graft. There is slight angulation of the bone, which suggests that a partial fracture has occurred, accounting for the callus excess.

Left Tibia: Dead Graft.—There is firm union, with great callus excess, angulation of the bone suggesting a partial fracture of the shaft. Along a part of its periphery the graft is inseparable from its bed, but at other points it is quite distinct.

The general result of these three experiments clearly indicates the practical superiority of a living graft, even if taken from another animal of the same species, over a dead bone-graft. In all three the living grafts gave a very good result, whilst in all the dead graft gave a bad or indifferent one. The fact is remarkable that, in all cases, fracture of the shaft occurred when a defect in half its thickness had been repaired by a dead graft. This only occurred once with a living graft, and only in a slight degree.

Nevertheless, *Experiments* 29 and 30 certainly prove that a dead graft may actually become inseparably united to its bony bed, and therefore the employment of such a structure cannot be regarded as useless if other material is unavailable.

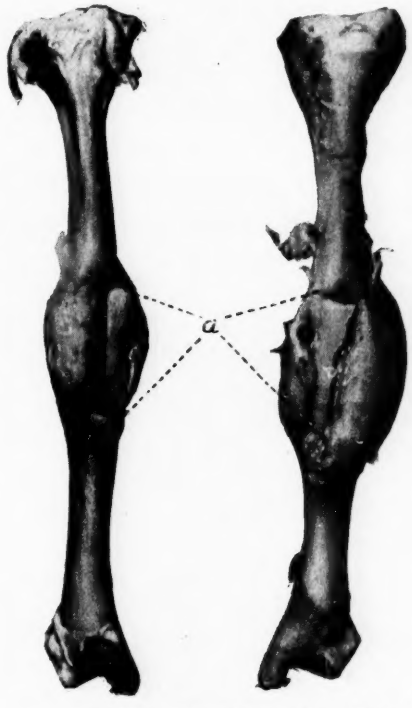

FIG. 179.—*Experiment* 30. Both tibias are from the same cat. On the left side is a homogenous living bone-graft. On the right side is a boiled graft. After 8 weeks. *a*, Graft.

SUMMARY OF EXPERIMENTAL RESULTS.

1. The most ideal graft is a piece of living bone used in its entire thickness.

2. Any kind of bone-graft gives better results when used whole than when broken up into small fragments.

3. Fragments of living bone, unless closely in contact with vascular tissue, act as indolent and passive structures, and display no osteogenesis.

4. Dust formed from living bone does not maintain its vitality.

5. Cortical grafts are far better than intramedullary.

6. An intramedullary graft, if small and loose, takes no part in repair, neither does it act as a splint. If it fits the marrow cavities of the fragments tightly, it hinders osteogenesis and is frequently subject to fracture.

7. The success of a living graft depends very largely upon: (*a*) The extent of its contact with living bone; (*b*) The accuracy of its apposition; (*c*) The firmness of its fixation.

8. Firmness of fixation is of paramount importance in the repair of defects in long bones by grafting.

9. A graft of dead bone (boiled), properly fixed by metal sutures, will give a better result than a living autogenous graft fixed by catgut alone.

10. Metal sutures and pins are useful in the fixation of many grafts. When properly applied they secure the necessary fixation, and there is no evidence that they hinder osteogenesis.

11. For use as pegs or nails there is no advantage in using living over dead bone.

12. Homogenous grafts, under favourable circumstances, act just as well as autogenous.

13. Dead bone-grafts are certainly inferior to living when used to fill defects in the long bones, but under favourable circumstances they become strongly incorporated into the living skeleton.

14. Provided that secure fixation of the graft to its bed is not disturbed, mobility of the limb favours osteogenesis, whilst immobilization hinders it. (Compare *Experiments* 3, 28, 29, 30, where no fixation apparatus was used, with *Experiments* 5, 25, 26, where the limb was held by the double-transfixion splint.)

III. CLINICAL METHODS: GENERAL PRINCIPLES.

Aseptic Technique.—Unfortunately there has arisen an idea that bone surgery requires a special form of aseptic ritual. The reasons for this are various. In the days before aseptic surgery, septic infection was so frequent and so severe as a result of operations upon bones, that no direct attack upon them was justified except as a matter of grave urgency. The contrast between the course of an open and that of a closed fracture in pre-antiseptic days was held to be evidence enough of the dangers of open exposure of bone tissue. When Lane first essayed to operate upon closed fractures, he had to face this prejudice, and in order to do so he established a very rigorous technique. The main features of this are that no finger touches either the wound or anything put into the wound; hæmostasis is by forci-pressure, and no ligatures are applied. This technique has been continued by many to the present day, and it is accountable for the fact that operative measures are limited to simple and superficial manipulations, e.g., the screwing of a plate on to the surface of a bone. Since Lane first began operating on closed fractures, aseptic technique has so greatly improved that his precautions are quite unnecessary. Rubber gloves are perfectly able to render finger-touch sterile, and in order to avoid the danger of tearing, cotton gloves may be worn over the rubber. Good bone surgery, and especially bone grafting, requires accurate fitting and fixing, and for these manipulations the fingers are necessary. The 'don't-touch-the-wound' technique, I venture to think, is not justified by its results; when by its use plates are screwed to bones, in many cases a subsequent sinus is formed, necessitating a further operation for the removal of plate and screws. The inefficient mechanical fixation imposed by the long instruments and absence of finger contact allows movement between the bones and the plate, thus causing an outpouring of fluid, which leaks through the old scar and then sets up secondary infection. Sound mechanical fixation, accurate fitting, and tight suturing are much more sure means of preventing infection than merely keeping the fingers out of the wound.

Exclusion of the skin surface from contact with the fingers and the instruments is very important. I have found that the simplest way of attaining this is as follows: The skin is prepared beforehand by shaving and by iodine. After the anæsthetic, iodine is again freely swabbed over the limb, and allowed to dry. Then a length of the tubular woven material known as stockingette,

which has been sterilized, is passed over the limb, fixed above by a bandage, and below it is tied together. The necessary incisions are then made through this material and the skin. The edges of the stockingette are fixed by Michel's Clips to the cut skin edges, and this is not disturbed until the very last stage in the operation. This method is not only very effective in excluding the skin from the wound, but it is very convenient when more than one incision has to be made, e.g., when both radius and ulna have to be exposed. The avoidance of forceps attaching the material to the skin is an advantage, because the operative field is not encumbered by these, nor is there any risk of their slipping off. The soft parts should be held aside by a suitable self-retaining retractor, so that they are bruised as little as possible by handling.

Latent Sepsis.—It is a matter of clinical and experimental evidence that the occurrence of a slight degree of sepsis does not prevent bone repair, though it generally hinders and delays it. It might therefore be thought that in dealing with the late results of an open septic fracture, it is not necessary to wait for the absolute subsidence of sepsis before attempting a bone-graft. But this is a very serious mistake. After a septic fracture, active inflammation may subside until only a sinus remains; or this may heal up and yet, in the scar tissue, real infective material of a very active sort remain latent, and any wide opening up of the tissues will cause this latent sepsis to spring into a most malign activity. In any case where a sinus remains, or any open wound, it is utterly unjustifiable to attempt a bone-grafting operation. The right thing to do is to extirpate the sinus, and then, when healing has occurred, to wait for several months, treating the limb by massage. If no septic relapse occurs under this treatment, then the further operation may be undertaken. Methods of treating the sinus by injections of bismuth or iodoform, which are quite good for ordinary purposes, seem to me rather dangerous here. They may subdue the sepsis enough to allow of healing, but there is always a great risk that germs are merely encapsuled and will be released into activity when the parts are opened up. It is much better to wait a long time, and to do several operations for the excision of sinuses and the removal of loose bits of bone, than to light up a severe septic conflagration by a premature bone-grafting, as this not only endangers the life of the limb, but certainly will cause loss of more bone from necrosis.

The Treatment of Scar-tissue.—After most septic gunshot fractures there remains much scar-tissue. This may be quite sound if it is left alone, but it is thoroughly bad material on which to rely for plastic surgery. The behaviour of cutaneous scars is most striking. A recent skin scar appears simply to melt away when it is part of a new operation wound or when it lies in a flap. Probably the same thing applies to deep scar-tissue. It can neither nourish itself nor afford nourishment to a graft when its connections are disturbed. Therefore it must be laid down as a primary rule for bone-grafting, that cutaneous scar-tissue must be replaced by healthy skin before the operation, and deep scars must be excised during the operation. This really constitutes one of the main difficulties of the problem, and it must be fairly met and not evaded. By cutaneous scar-tissue I mean any considerable loss of substance which has been covered over by a mere epithelial cicatrix. If this is small in

extent, it should be excised, the skin freed from underlying bone, fatty connective tissue interposed, and the skin sewn together so as to heal by first intention. If the scar is larger, a flap must be made, either from the limb itself or from some other part of the body, and time given for this stage in plastic repair to be complete before the bone is touched.

I would repeat that before any bone-graft is undertaken for the results of a septic fracture, three things are necessary, or perhaps I should say four. These are:—

1. Sinuses must be healed soundly.
2. Cutaneous epithelial scars must be replaced by thick healthy skin.
3. The skin must not be adherent to the bone: all retracted, adherent scars must be obliterated by fat.
4. Sufficient time must be given for these measures to produce consolidated repair; probably four to six months.

The observation of these precautions will not only secure smooth healing of the bone-graft, it has another advantage. Whilst waiting for superficial plastic repair, the bone often mends itself by a growth from the divided ends and by osteogenesis from fragments left in the gap.

The Source of the Graft.—In the great majority of cases, defects in continuity of the bones should be filled by autogenous grafts. In order to supply these, there are three readily available sources, viz., the crest and anterior portions of the tibia, the upper part of the fibula, and the ribs.

The Use of the Tibia.—Of late years the crest and inner surface of the tibia has quite rightly been the most favoured source of autogenous grafts. From it may be fashioned a piece of bone up to ten inches in length, and having a square section half an inch wide in each direction. The crest of the tibia is the strongest piece of dense bone of suitable length in the body. On two surfaces periosteum can be preserved, and endosteum on the other two. Its tissue is firm, and allows of firm holding by pegs, wire sutures, or bolts. Against these advantages must be placed two drawbacks. The very dense bone of the tibial crest is poorly supplied with both blood-vessels and osteoblasts, and therefore it cannot furnish much osteogenetic activity. Secondly, the removal of the strongest part of the tibia has often led to fracture of the remaining part of the shaft. Neither of these disadvantages is of determining importance. The graft is so strong and can be fixed so securely, that its slow growth in thickness is not of any moment. The liability of the rest of the bone to fracture has only to be recognized to be guarded against, by providing a light plaster case for the affected leg if the patient is to walk upon it within six weeks of the operation.

When great strength is not required in a graft, as in the filling up of gaps in skulls, it is better to avoid the crest of the tibia, and to take a flat piece from the inner surface.

The Use of the Fibula.—A long length of graft can be obtained from the fibula much more readily than from the tibia, and with much less traumatism. Such a graft seems to be capable of more rapid increase in thickness than is the case with a bit of tibia. Its use is therefore indicated when a long piece of either the femur or humerus has been removed, as for example in resection for an endogenous tumour. It is also very useful in the replacement of a large

gap in either radius or ulna—that is to say, when the defect is too great to be filled by a piece taken from half the thickness of the injured bone itself. Another possible indication for the use of the fibula is as a substitute for the head of the femur. In this case the head of the fibula would be used, with three inches of the shaft ; the latter would be driven through the trochanteric region of the femur at the proper angle.

The Use of the Ribs.—The rib has often been used for grafting. The tenth rib can readily be spared, and it is easily removed and as easily cut. Its natural bend has suggested its use for the substitution of curved bones, e.g., the jaw. But it is very doubtful whether it is really suitable for grafting purposes when the attainment desired is that of a strong permanent bone. In the first place, in many instances when it has been used (e.g., McWilliams), it has quickly become absorbed. Secondly, its spongy structure makes it difficult to fix firmly by wire or pegs. We cannot ignore the factor of individuality in bones. A rib is not designed to bear a heavy strain, and when transplanted, it never seems to grow into a dense hard bone like one of the long bones of the limbs.

The Composition of the Graft.—Whatever view may be taken of the exact function of the periosteum and medulla, there can be no doubt that the preservation of both these structures is a matter of importance in taking a living graft. Although new bone is probably the product of osteoblasts of the graft, nevertheless it is on the surfaces of the dense bone, i.e. from epiosteum and endosteum, that this new bone is laid down. The periosteum and marrow protect these surfaces, and act as vascularizing tissue to them.

The preservation of the periosteum on a graft is a simple matter. But there are two points of detail which are important : (1) All muscle and tendon insertion should be dissected off the graft, as these greatly delay the establishment of new vascular supply ; (2) The periosteum should be cut longitudinally by several incisions in order to release the underlying osteoblasts. The marrow is of less importance than the periosteum, and it is not worth while to sacrifice the strength of a tubular graft by splitting this down the middle. But access to the marrow cavity can be readily secured at points other than the two ends of the bone, by making several drill-holes through the compact tissue into the medullary cavity.

Homogenous and Dead Bone-Grafts.—The indication for the employment of other than autogenous grafts is perfectly well defined. It is when the defect to be made good includes all or part of the articular end of the long bones where such articular surface depends for its function upon its exact shape and its cartilaginous covering. The best examples of the kind are the head of the femur and the lower end of the humerus. For such defects no autogenous graft can supply an efficient substitute, and there have been a sufficient number of successes in the use of both of homogenous and dead grafts to justify their employment.

The homogenous graft can seldom be obtained from an amputated limb, but must be taken from a corpse. The subject from which it is removed should have been free from any infective disease, the best being one who has been killed by accident. The possibility of accidental post-mortem contamination should be guarded against by taking a culture from the graft, and not using

the latter for a period of twenty-four hours, when the incubated culture will have had time to reveal the presence of pyogenic organisms. During this period the graft should be kept in a sterile receptacle in the ice chest.

In the preparation of a dead graft, the easiest method is to take the bones from a corpse, and to subject the same to prolonged boiling after maceration. The other alternative, which has been adopted by König with good results, is to have a part fashioned out of ivory. The relative advantages of a sterile human bone and of an ivory prothesis cannot be stated positively as the result of experimental evidence. Ivory in large bulk (e.g., enough to make the upper end of a femur) is expensive and difficult to obtain. On the other hand, its great density makes it less readily absorbed than would be the case with more open bone. But we do not know whether this density may not have the definite disadvantage of hindering the ingrowth of living tissue necessary for the functional incorporation of the graft. The extraordinarily rapid and firm attachment of dead to living bone, which has been demonstrated in the above experiments, would seem to me to indicate that if living bone cannot be obtained, then sterilized human bone is the best substance for the graft. The object for which ivory is of undoubted value is for the fashioning of pegs, nails, bolts, or screws.

Previous Preparation of the Graft.—One fact about the behaviour of living grafts is very prominent. The dense bone, which is essential for strength, acts with extreme indolence, and no active osteogenesis such as can be demonstrated by the *x* rays occurs from it for many months. Whether this is due to the death of the osteoblasts, or to its want of vascularization, is uncertain; but it would seem to be a reasonable thing to subject the portion of bone destined for a graft to previous treatment, in order to increase both its vascularity and cellular content, and to render easier the communication between its interior and the tissues of its future bed.

Lately, I have been carrying this out as follows: At a period of about four weeks before the injured limb will be ready for the graft, the tibia from which the graft is to be taken is exposed by a flap incision. The periosteum is cut by longitudinal incisions for every quarter of an inch of its exposed surface, and then the cuts are deepened by the saw. In these cuts a small drill ($\frac{1}{16}$-in.) is used to bore holes right into the marrow cavity at distances of about three-quarters of an inch. In this way the area of the future graft, six inches long, will be scored by five or six incisions and perforated by about thirty holes. At the end of four to six weeks this area of bone is much thicker than before, and it is also red and vascular instead of being very white and bloodless. Enough time has not yet elapsed to show whether this preparation of the graft leads to increased rapidity and degree of osteogenesis, but the facts already observed encourage the hope that this is the case.

Cutting the Graft.—It will be sufficient to describe the taking of a tibial graft. The area from which the graft is to be taken should be exposed by a long flap incision. The length of the graft should allow of a generous overlapping of its ends beyond the gap to be filled, to provide for secure fixation and a large area of apposition with the living bone at both ends. At least an inch of overlapping should be provided for at each end. The area of the

graft should be marked out by a scalpel-cut through the periosteum, but this periosteal incision should be about a quarter of an inch wide of the line of the saw-cuts. This allows an edge of periosteum to project all round the graft for the purpose of suturing the latter to the tissues of the bed. If the graft is required merely to fill a defect in the skull, or in a small bone, and not to bear much strain, it is sufficient to take a strip from the inner surface of the tibia, not including the crest. But if it is intended to supply a long gap in the humerus, femur, or tibia, then the strong tibial crest must be included, and the graft will have a square or a triangular section.

The actual cutting of the graft should be made by a circular saw actuated by an electric motor. The motor saw outfit now in most general use is that of Albee. It consists of a very small motor (about $\frac{1}{25}$ horse-power) in a case held in the hand, with the saw directly attached by a rigid shaft. The disadvantages of this are that the weight of the motor has to be held in the hand, and that the available power is so small that it is difficult to deal with a thick tibial crest. Preferable to it, I think, is a more powerful motor on a stand, connected with the saw by a flexible cable. The motor I use is of $\frac{1}{10}$ horse power, and an arrangement is provided by which either a direct drive can be employed at high speed (1500 revolutions a minute), or else a geared drive can be used, which reduces the speed to 300 revolutions per minute, with a corresponding increase in power. This slow speed is of advantage not only in being more manageable and more powerful, but in producing less heat in cutting the bone.

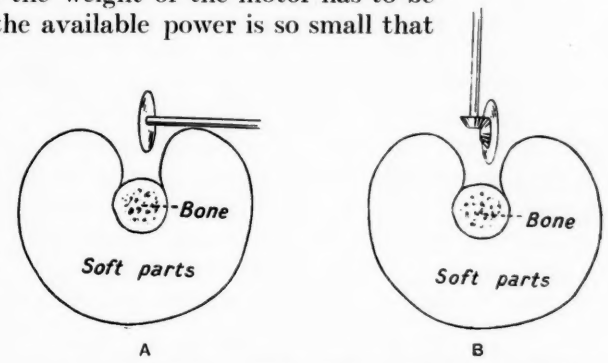

FIG. 180.—A, Diagram of ordinary circular saw, cutting at right angles to its shaft. B, Author's saw, cutting parallel to its shaft.

The ordinary circular saw cuts in a plane at right angles to the shaft which propels it, and this often makes it difficult to deal with a bone surrounded by soft parts, because the shaft comes in contact with the latter. This difficulty is overcome by using a saw which I have designed, in which the blade works parallel with its actuating shaft (*Fig.* 180).

The use of a twin saw makes it possible to cut a graft with exactly parallel sides, and this can then be fitted into a slot cut by the same saw (*Fig.* 181). It is, however, rather doubtful whether there is much advantage in this, and there are some disadvantages. The saws have a certain

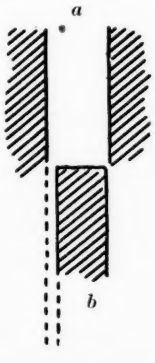

FIG. 181.—Diagram showing oose fit of the graft in its bed when both graft and slot are cut by the same twin saw. The space between the dotted lines indicates the thickness of the saw-cut. *a*, Slot. *b*, Graft.

thickness, and if the same twin saw be used to cut both the graft and its bed, then the graft will be loose by just the thickness of the saw-cuts. Most commonly the tibial graft is taken for its strength, and then it must be cut by two distinct cuts at right angles to one another, one on the inner and the other on the outer surface of the bone (*Fig.* 182).

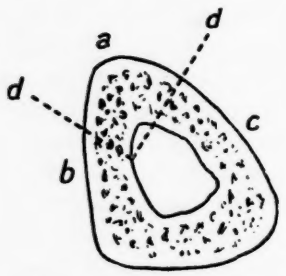

FIG. 182. — Diagram of transverse section of tibia, showing saw-cuts used for taking a strong graft. *a*, Crest. *b*, Outer surface. *c*, Inner surface. *d*, Dotted lines showing direction of saw-cuts.

The upper and lower ends of the graft should be marked at each angle by a drilled hole, and these are then joined by a saw-cut (*Fig.* 183). The longitudinal saw-cuts need not be so deep as to free the graft completely. In fact, it is better to complete this by the use of a chisel. The latter tool subjects the bone to less traumatism than the saw, and it does not choke up its canals with bone dust.

For cutting a graft from small bones, e.g. the ulna or radius, and for the shaping of the bone ends when these can be lifted clear of the soft parts, a metal fret-saw is much more convenient than a motor saw.

The Preparation of the Bone to be Repaired.—The matter of bone-grafting is comparatively easy when it can be done with tissues which are normal, and into a bone which is not displaced. Such conditions, for example, as are presented when the upper end of the humerus has been removed for an endosteal sarcoma. It is most difficult, on the other hand, when done to repair defects left by injury accompanied by sepsis.

The matters of latent sepsis and untrustworthy scars have already been referred to. But other difficulties still remain to be overcome. These are due to the presence of deep dense scar-tissue, and to the gross deformity of the bone which has resulted from loss of substance and the contraction of soft parts. Such difficulties would be great in proportion to the absence of support by a parallel bone—e.g., in the femur, the period during which sepsis has been present, and the absence of proper orthopædic treatment.

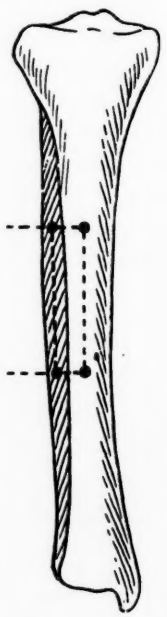

FIG. 183. — Diagram showing the four drill-holes and four saw-cuts used in cutting a strong tibial graft.

In the matter of one of the forearm bones, when its fellow remains sound, there is very little distortion. Sometimes, too, the fibula remains intact and serves to splint the tibia. In these circumstances there is no necessity for special correction of bone deformity before laying the graft. If, however, there is much deformity, and if it is intended to correct this, and not merely to splice a crooked bone, then this correction must be very carefully undertaken as a preliminary to, or as the first stages of, the operation. Suppose, for example, the femur has been broken and four inches of its substance lost, the ends of the bone are close together,

buried in deep fibrous tissue, and there may be both lateral and axial displacement. These conditions are quite common, and impose so many difficulties, that hitherto the possibility of bone-grafting has hardly been considered, and the unfortunate patient is simply left with his deformed leg four inches short and with a false joint.

There are many less extreme cases, where the bone to be mended is grossly deformed, and in which the correction of the deformity must precede any attempt at grafting. The necessity for this correction is threefold: First, it will ensure a straight limb of full length; secondly, it will make the act of grafting much simpler; and thirdly, it will impose much less strain and tension on the connection between the graft and its bed.

Consider, for example, the case of a broken tibia in which there is a gap originally of four inches, reduced perhaps to less than an inch, with much angulation, when treatment is begun. If a grafting operation is undertaken forthwith, there will be a most tedious, difficult, and laborious manipulation before the bones can be straightened and extended to a proper length. In fact, in many cases these difficulties will be found to be insuperable. But if proper extension be applied to the limb, then, after an interval of about seven days, the scar tissue will be stretched and the alinement corrected. In bad cases the lower end of the bone should be transfixed by a steel pin, or grasped by a screw clamp, and then pulled upon in the correct line by a suitable weight of ten to fifteen pounds for the period named. If further correction is necessary at the time of the grafting operation, a second transfixion pin can then be placed through the upper fragment, and by means of a screw extension apparatus the two parts of the bone can be forcibly separated and held in position during the grafting. This apparatus can be left in place for some days. After the operation it will serve to steady the mended bone and to relieve the bone sutures of all tension.

In other cases where the bone is not so large, or the difficulty of the reduction not so great, one or other of the simpler extension instruments may be used.

The necessity for corrective extension of a broken bone prior to grafting is not merely to make easier the grafting operation. It is to overcome the tension which would otherwise be thrown on the graft and its fixing sutures, which tension will greatly endanger its fixation.

Methods of Fitting the Graft to its Bed.—The accurate fitting and fixing of the graft to its bed is a very important part of the operation. The evidence of the experimental work which I have detailed has impressed me very strongly with this point. The greater accuracy and firmness that is used in fitting the graft, the smoother will be the healing and the quicker will be functional recovery. Vital union will depend upon the surface contact between the two parts of bone, and upon fixation being both firm and lasting. In special cases, of course, special fitting methods may be used, but for the repairing of a gap in the length of a tubular bone, the methods of fixing may be described under six different heads.

1. *The Inlay Graft.*—In this, a narrow strip of bone is cut, either from one of the fragments of the damaged bone or from the inner surface of the tibia. It is laid into a corresponding groove cut in the bed. This method is

only suitable for one of a pair of parallel bones, where there is neither much gap nor much displacement. It is mechanically weak, and leaves a large gap to be filled by new bone.

2. *The Intramedullary Graft.*—This method is much the easiest, as the graft will only require to be roughly shaped as a peg at each end and fitted into the marrow cavity of each fragment, requiring no other fixation. The evidence, however, both clinical and experimental, shows that this method does not always succeed. It is somewhat weak and insecure, and osteogenesis is very slow. Union of the graft with its bed is not so firm or so rapid as in the cortical methods, and there is a real danger of the graft becoming broken.

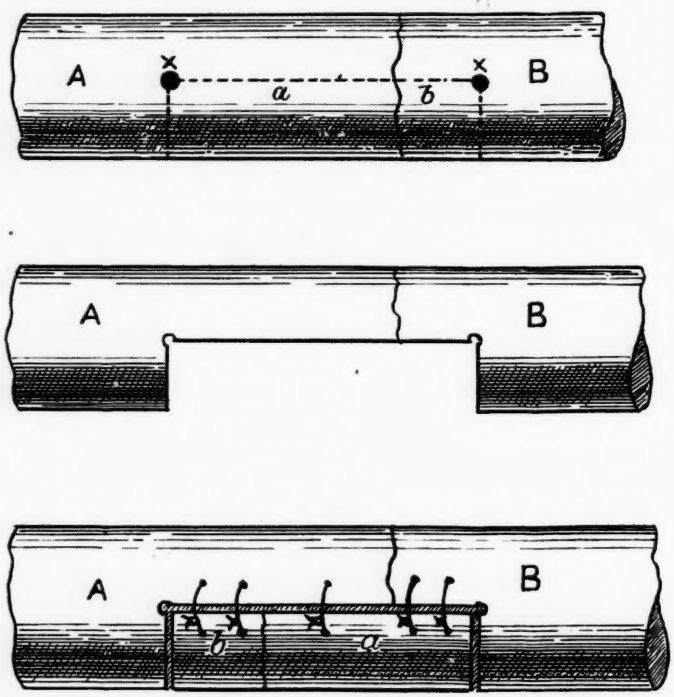

FIG. 184.—Half-cylinder graft, fixed by wire sutures: bone-grafting by the cutting of unequal pieces from the fragments of a fracture, and then reversing them. In the upper figure the fragments A and B are bored at points x x, and cuts made so as to take a piece *a* from A more than twice as long as the piece *b* from B. In the middle figure these pieces are removed. In the lower figure the piece *a* has been placed in the angle of B, and the piece *b* in the angle of A, and there sutured by wire sutures.

3. *The Half-Cylinder Graft.*—In this the bed is cut through for half its thickness and a piece removed about an inch long. The graft is cut of about half the thickness of the bone to be mended, and its two ends are fitted into the steps cut in the fragments. This method is one which combines easy performance with considerable mechanical efficiency. It was the method which gave the best results in the above experiments. It fills up the gap by a piece of bone half the thickness of the shaft, and only leaves a half-thickness to be restored by new bone. It permits of very firm fixation by means either of wire sutures or of bolts (*Figs.* 184, 185).

4. *The Cylinder Graft.*—This and the following methods are only possible when the graft can be cut from a bone of the same thickness as that to be repaired. Practically, they will be limited in autogenous grafting to the repair of the forearm bones by a piece of fibula; but they can be used for the larger bones if a homogenous or dead graft is employed. The cylinder graft is illustrated in *Experiment* 1. A section of the bone is cut as the graft, just long enough to fill the gap, and the tension of the bone and that of the surrounding soft parts is enough to keep it in place. It is only suitable for the repairing a long gap in one of the forearm bones when the companion bone is quite sound.

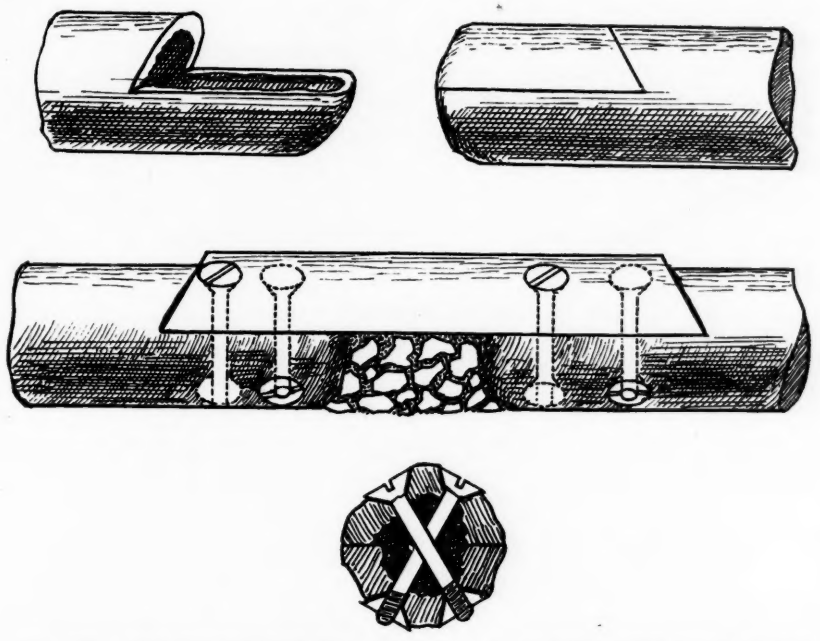

FIG. 185.—Half-cylinder graft fixed by bolts. In the upper figure the bone ends are shown cut for the reception of the graft. In the middle figure the graft is seen bolted in place, the pieces of bone cut from the original fragments being divided up and placed in the gap. The lower figure shows the junction of the graft and the bone in transverse section.

5. *The Mortised Cylinder.*—This is the same as the last, except that the graft is cut about two inches longer than the gap it is to fill, and each end is cut away in half its thickness for an inch. A corresponding step is cut in each fragment, and the graft fitted in place.

6. *The Pegged Cylinder.*—This is similar to the cylinder graft, but there is provided in its axis an ivory or dead bone peg which fits into the marrow cavities of the two fragments.

The advantage of the cylinder grafts is that they entirely fill the gap, and no cavity is left for restitution by new bone.

The Fixation of the Graft.—Every type of graft used to fill a gap in a long bone must be securely fixed. Some form of suture will be necessary in all except the medullary or cylinder grafts. This suture ought to be of some

metallic material, or of ivory. My reasons for this have been stated in the experimental section.

It seems to me quite unreasonable to deal with rigid skeletal structures by materials such as catgut or kangaroo tendon, that is, unless the graft is in such a place that there will be no tendency to its displacement, e.g., in a gap in the skull; here no suture at all will be necessary. Either use no suture to fix a bone, or else use a metal or ivory fixation material.

The Use of Wire.—The best material is soft iron wire, which I now employ without any plating. It is much cheaper and stronger than silver and less irritating to the tissues than copper or bronze.

The best way to use it is to place it as a mattress suture through two holes in both the graft and its bed. This, however, is often impracticable when dealing with small bones, and then one or two turns of wire round the whole shaft will act very well. A groove may be made by a file or saw, and

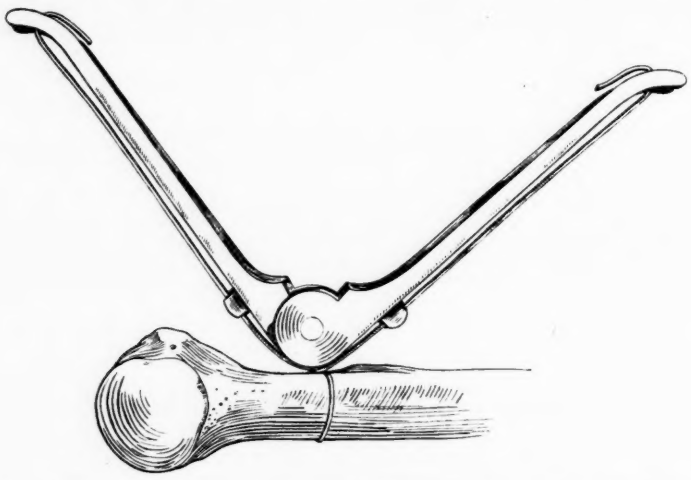

FIG. 186.—Author's wire-tightening forceps. The wire is passed round the bone, its ends are crossed, then laid in slots in the sides of the forceps, and turned round the V-shaped ends of the handles. When these are closed together the wire is tightened, and can then be twisted.

in this the suture lies snugly. It is very important that wire sutures should be so tied that no slack is left which may allow play between the bones. If only thin wire is used (No. 20 Standard Wire Gauge), long pieces should be employed, passed twice round the bone, and by means of the long ends, grasped by forceps, pulled quite tight before being twisted and cut short. If stout wire (No. 14 S.W.G.) is used for a big bone, it ought to be drawn tight before twisting, for which purpose I have devised a special instrument (*Fig.* 186).

Metal Pins.—Ordinary cotter-pins are very useful for small bones. These are $\frac{1}{8}$ inch in thickness, and split, so that when they have been passed through the bone and the graft, a small washer is slipped over the end, and the halves of the pin are separated, cut short, and pressed back. This device has been illustrated in the above experiments.

Metal Bolts.—Bolts which excellently serve all purposes for bone grafting are made of iron $\frac{1}{8}$ inch thick and in length from $1\frac{1}{2}$ to 4 inches ; the head of the bolt is cut for a screw-driver, whilst the nut may be either hexagonal or milled. The graft is held to the bed by a catch forceps. Both are drilled through in two or three places, the direction of the drill-holes being in different radii of the cylinder. The bolts are placed before removing the forceps. The nuts are screwed home tightly after countersinking the holes, and the projecting part of the bolt is cut off by shears.

Ivory Pegs or Bolts.—Instead of using metal pins or bolts, these may be made of ivory. The advantage of this is that the substance actually becomes incorporated in the bone, and I think that in future, as we become accustomed to the use of this material, it will be more and more used. I have now four types of ivory pegs. First, the intramedullary peg, which is really a dead bone graft. Secondly, a square or round nail, which should be left rough and not polished. Thirdly, screws cut from ivory after the pattern of metal screws ; to use these, the hole made in the bone and the graft must be prepared by having a female thread cut in by a special tap. Fourthly, ivory bolts ; these are thicker than the metal bolts, namely, $\frac{5}{32}$ inch, and the nuts are also wider.

Treatment of Periosteum and Fragments.—In all manipulations of the injured bone the periosteum should be freely raised from those parts of the bone which have to be exposed. This is for two reasons : first, because the mere raising of the periosteum stimulates the underlying bone to osteogenesis ; and secondly, because the great value of the periosteum is due to its blood-supply. If the membrane is left with its connections to the soft parts undisturbed, then its power as a vascularizing membrane will be undiminished ; whereas, if the soft parts are first raised from the periosteum, this act will temporarily rob the bone of part of its blood-supply.

In all ways of fitting a graft into a bone defect, except that of intramedullary pegging, there are fragments cut from the bone ends in shaping these for the reception of the graft. These should not be discarded, unless the graft completely fills the gap. They should be placed in the gap, closely packed, in the manner shown in *Fig.* 185. It is true that these fragments will not play any very active part in osteogenesis ; but they will in time become incorporated with the rest of the bone, and they serve to make the time of final consolidation shorter.

Suture of the Soft Parts.—After the graft is fixed in place, the periosteum of bed and graft should be sewn together, if possible by catgut. Then the muscles, and finally the deep fascia, are carefully sutured over the bone. The more deeply the mended bone is buried in soft tissues, the less danger is there of secondary infection taking place from the skin surfaces. Also, careful deep suture will obliterate any dead spaces, and prevent the formation of blood-collections, which hinder the bone from becoming attached to the soft parts and vascularized by them. Drainage by strands of silkworm-gut for forty-eight hours is a wise precaution whenever there has been much oozing.

After-treatment.—All surgeons are agreed that it is necessary that a bone which has been grafted should be immobilized for several weeks or months after the operation. If the graft has not been firmly fixed to its bed

by metal sutures, then, in order to carry out this immobilization, it will be necessary to encase the limb in plaster of Paris, including the joints above and below. In fact, some surgeons advise that the whole limb should always be encased in plaster from the girdle to the digits. But there are great drawbacks to this procedure. The wound cannot be inspected, or a drain removed, without cutting off the plaster. Whatever functional disability has existed before the operation will be greatly increased by the rigid case. Muscles will atrophy, and the joints become very stiff. Further, it is a matter of common observation that absolute immobilization of a whole limb leads to atrophy of the bones themselves, and this at the very time when the one thing needed is new bone growth. I have shown, too, by experimental evidence, that provided the graft is securely fixed to its bed, new bone growth takes place better when no immobilization is employed. I would therefore urge very strongly that the main factor in immobilization should be the actual fixation of the graft to its bed. If necessary, this may be supplemented by the use of long steel plates, such as those shown in *Experiments* 22 and 23, these being bolted to the whole thickness of the bone, and not merely attached by superficial screws. But however it is done, the fixation of the graft should be internal and not external.

A light supporting splint is used for a few weeks, and when the wound is healed, the limb is taken down every day, and subjected to light massage with movements of the joints. In this way the nutrition of the muscles and the flexibility of tendons and joints are preserved, whilst the formation of new bone is encouraged.*

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* This Paper, together with a list of the author's clinical cases, formed the Jacksonian Prize Essay for 1917. Owing to exigencies of space the latter portion is postponed to a future issue. The expense of the experimental portion of this work was defrayed by a grant from the British Medical Association to whom the author wishes to express his thanks.

A CASE OF OSTEO-ANEURYSM.

DIFFUSE TRAUMATIC ANEURYSM IN THE SURGICAL NECK OF THE HUMERUS.

By R. LAWFORD KNAGGS, Leeds.

Osteo-aneurysm is an old term that is used to describe pulsating tumours of bone. It may be presumed that the word was originally employed because the pulsation in such cases was expansile and was sometimes associated with a bruit. That the idea of aneurysm in some form or other was believed to be a possibility is shown by the report on Bickersteth's case in the *Pathological Society's Transactions*, xix, 348. A careful perusal of the case, however, leaves the impression that it was one of new growth, notwithstanding the following report by two well-known surgeons of a past generation: "We entirely agree with the author in his description of this specimen, and look upon it as an admirable example of aneurysm commencing in the lower extremity of the tibia, expanding the bone, and extending backwards into the muscles and soft parts behind the tibia." This was all. Only the macroscopic appearances were described, and no histological examination seems to have been made.

At the present time pulsating tumours of bone are very generally thought to be true tumours, and undoubtedly those usually met with are growths of varying degrees of malignancy, and also of very different macroscopic and microscopic features. Probably there is no real belief nowadays in an aneurysm of bone which has the same pathology as spontaneous or traumatic aneurysm elsewhere. The best accounts of osteo-aneurysm are to be found in the older text-books: in the more modern works on surgery there is a tendency for the subject to be treated very shortly or to be omitted altogether. But in none have I been able to find a case referred to in which the description made it clear that a blood tumour communicating with the interior of an artery, and having a definite circumscribed sac, was the cause of the symptoms.

I hope, however, to show that such cases may occur, and as they are most likely to be traumatic aneurysms, and not unlikely to result from gunshot injuries to the bones, the recognition of that fact at the present time is not without its value.

Pte. E. E. W. was wounded in the left shoulder on Sept. 15, 1915. He was treated in a general hospital in France for thirteen days, was then sent home, and was admitted into the 2nd Northern General Hospital on Oct. 2.

A bullet had passed through the surgical neck of the left humerus. The wound of entry was behind the shoulder over the posterior fibres of the deltoid, and the bullet had passed out through the centre of the upper part of the biceps. Both wounds were healthy, and apparently superficial, when he was

admitted. On the night of Oct. 21 the man had a bad night owing to a great deal of pain in the shoulder, and next morning pulsation was first detected about an inch above the exit wound. Careful examination showed that the upper part of the shaft was considerably enlarged, and that this enlargement was the subject of expansile pulsation, which was at once perceptible when the bone was held between the fingers of both hands. The main artery could be felt to be quite normal as it coursed over the internal aspect of the swelling. No bruit could be made out, and there was no thrill.

A skiagram that had been taken on Oct. 16 (*Fig.* 187) showed a large irregular aperture in the surgical neck, with comminution of the internal surface, the fragments being displaced as if they had been forced outwards by the

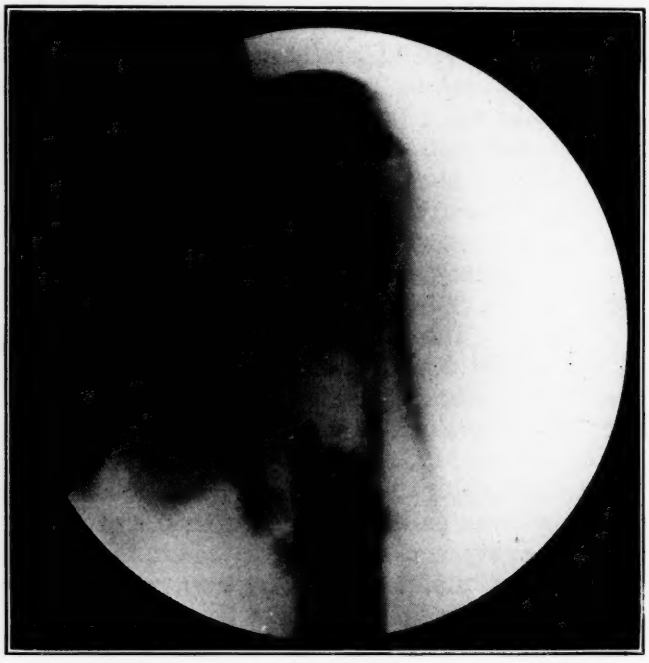

FIG. 187.—Skiagram taken on Oct. 16.

explosive effect of the bullet. On Oct. 31 an enlarged gland was noticed in the supraclavicular fossa. The general swelling of the shoulder that had followed the wound had now completely subsided, and the increasing expansion of the bone showed as a definite rounded tumour about the size of a cricket ball, altering the normal contour of the limb.

Another skiagram, taken on Oct. 30 (*Fig.* 188), confirmed the increased expansion of the bone and the further enlargement of the space in the interior.

The case, being one of great interest, was seen by most of my colleagues, and there was a general agreement in a diagnosis of rapidly-growing endosteal sarcoma. When the serious nature of the condition was explained to the patient, he at once agreed to lose his arm.

On Nov. 1 he was anæsthetized, and an incision was made through the deltoid into the tumour. A mass of black clot was evacuated; but nothing was seen that looked like tumour tissue. The evacuation of the clot was followed by very free arterial bleeding, and the cavity was at once firmly packed whilst the position was reconsidered. It was felt that even yet there was no certainty that we had not a growth to deal with, for it is well known that in some cases only careful examination of the cyst wall may reveal that a blood cyst of bone is really due to sarcoma. Moreover, if the condition were not due to growth, an attempt to save the arm would be attended by such danger that amputation later—when the patient's condition might have been seriously impaired by secondary hæmorrhage and suppuration—would probably be

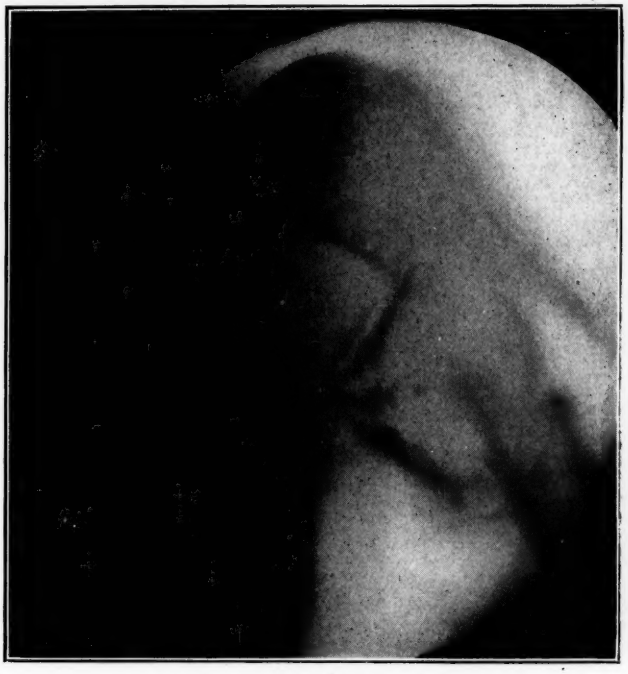

FIG. 183.—Skiagram taken on Oct. 30.

imperative. So it was decided to proceed, and the interscapulothoracic amputation was performed by Littlewood's method, i.e., from behind. The operation was well borne; a rapid recovery followed, and after a period at a convalescent home the patient was signed up as fit for the adaptation of an artificial limb on Feb. 21, 1917.

The tumour was examined immediately after the operation. The contents were black clot, and as this was being turned out, towards the end, a piece of dark red membrane, equal in extent to about one square inch, was seen amongst it. This membrane was evidently a portion of the sac of a traumatic aneurysm. To anyone who had seen many cases of traumatic aneurysm —as I suppose most surgeons to the large military hospitals have—the

character of this membrane was conclusive. From the moment of its appearance no doubt whatever was felt as to the real nature of the case. Therefore at a later date a more careful examination of the interior of the cyst was made, and a portion of the anterior wall removed in order to expose the cavity more

FIG. 189.—Drawing of the specimen.—The position of the remaining portion of the original aneurysmal sac is indicated at the extreme upper limit of the bone cyst. Miss Wright has represented it at a lower level than its true one, for it was concealed behind the overhanging edge of the cyst wall and could only be seen by looking upwards through the opening. The small sketch is an enlarged representation of the cup-shaped cavity. The little dark spot in the right lower quadrant is the aperture which had the appearance of an opening into a small vessel. The central discoloration is probably due to traces of adherent clot over a roughness caused by underlying inequalities of bone.

thoroughly. This was rewarded by the discovery of a portion of the original aneurysmal sac in the highest part of the cavity (*Fig.* 189). It was situated beneath the anterior wall of the cyst in the upper part of the surgical neck. It formed a hollow in the cancellous tissue big enough to receive, as in a cup, a very

small Barcelona nut. Its lining membrane was smooth and shiny, of the same dark-red colour as the piece of membrane described above, and it was adherent to the bone to which it was closely applied. On one side of this cup, by the help of a magnifying glass, a small aperture could be seen which was suggestive of an opening in a small vessel. The smooth glistening character of this membranous lining was in sharp contrast with the rough, irregular, and dark-coloured remains of old clot, which covered the rest of the interior of the cavity in the bone, and through which the bone splinters projected.

It only remains now for the pathological examination to be recorded. Portions from the wall of the cyst were examined by Capt. M. J. Stewart, the clinical pathologist at the General Infirmary and of the East Leeds War Hospital, and by Dr. O. C. Gruner. Both agreed that there was no evidence of sarcoma to be found, and I now give the report which Dr. Gruner has kindly drawn up. The gland unfortunately was lost.

> *Report on Wall of Bone Cyst.*—Two portions of the wall were taken at different places. The thinner portion is composed of laminated blood-clot in which there is some admixture with fibroblasts. The thicker portion shows attenuated bone trabeculæ rather widely separated from one another by a tissue which has a homogeneous matrix and is occupied by granulation tissue. Lymphocytes and small plasma cells occur between the capillary loops. There is no evidence of sarcoma. The wall of the cyst appears therefore to be constituted by organizing ossifying granulation tissue.

There can be no doubt that this was an instance of a traumatic aneurysm occurring in the interior of the humerus, and that it probably ruptured and became diffused on the night of Oct. 21, when the patient suffered for the first time since his admission with severe pain in the shoulder.

In conclusion, and with much pleasure, I would like to acknowledge the assistance received in this and many other anxious cases from my Commanding Officer and old colleague, Lieutenant-Colonel Littlewood.

GUNSHOT WOUNDS OF THE KIDNEY AND URETER AS SEEN AT THE BASE.*

By Colonel ANDREW FULLERTON, C.M.G., A.M.S.,
Consulting Surgeon, British Expeditionary Force.

In this article the term gunshot wounds will be used in the widest sense to include all injuries produced by the missiles employed in modern warfare. The remarks which follow are based on the examination of 42 cases seen at the base. Many of these have been imperfectly studied, but this is unavoidable under the conditions obtaining, even so far back from the firing line. Under stress of work it is impossible to carry out elaborate investigations, and the urgent necessity for evacuation of patients, to make room for others arriving from the front, has prevented the final results in many cases being ascertained. Enough material has, however, been available to indicate the lines on which further investigation may be carried out. A short summary of cases will be given at the end, so that reference may be made to any case mentioned in the text.

CLASSIFICATION.

Wounds of the Kidney.—These may be classified into: (1) *Those involving the Hilum*; and (2) *Those Involving the Parenchyma of the Organ.*

1. Wounds Involving the Hilum.—These may be divided into (*a*) Those involving the blood-vessels supplying the organ; and (*b*) Those involving the pelvis.

a. Those Involving the Vessels.—If the main renal artery is divided, the patient may die of hæmorrhage before he reaches the clearing station or the base. If one of its branches is divided, the hæmorrhage may not be sufficient to cause death. In that case the area of the kidney supplied by this branch will undergo necrosis. It is important to remember, in dealing with injuries to the blood-vessels of the kidney, that the arteries are terminal or end arteries, though the veins anastomose. Division or blocking, therefore, of an artery going to the organ will be followed by death of the area of distribution of that artery. The importance of this fact was brought to my mind some years ago. I had occasion to explore a kidney in a healthy male subject, and an aberrant artery to the upper pole had to be divided before the organ could be brought into view. Some weeks later I had again to operate on this kidney, and I now found that a large part of the upper pole was of a dull yellowish-white colour, and this area was sharply marked off from the remaining healthy portion. In the same way, an injury in the parenchyma to a branch of the renal artery will be followed by necrosis of the part supplied by it.

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* A lecture delivered before the Boulogne Medical Society, on June 22, 1917.

b. Those Involving the Pelvis of the Kidney.—Wounds involving the pelvis of the kidney alone are not very frequent, as other complications are likely to be present. These wounds allow of the discharge of urine into the perirenal tissues and through the wound in the parietes. If the peritoneal cavity has been opened by the missile, urine may leak into it and produce peritonitis.

2. Wounds of the Parenchyma of the Kidney.—These may be so severe and extensive as to reduce the organ to pulp, and all grades between this condition and a small perforating wound, produced by a bullet or a small fragment of shell, are seen. Most of the more extensive wounds are dealt with at the casualty clearing stations, but those of less severity are frequently treated at the base. The character of the wound will depend on the

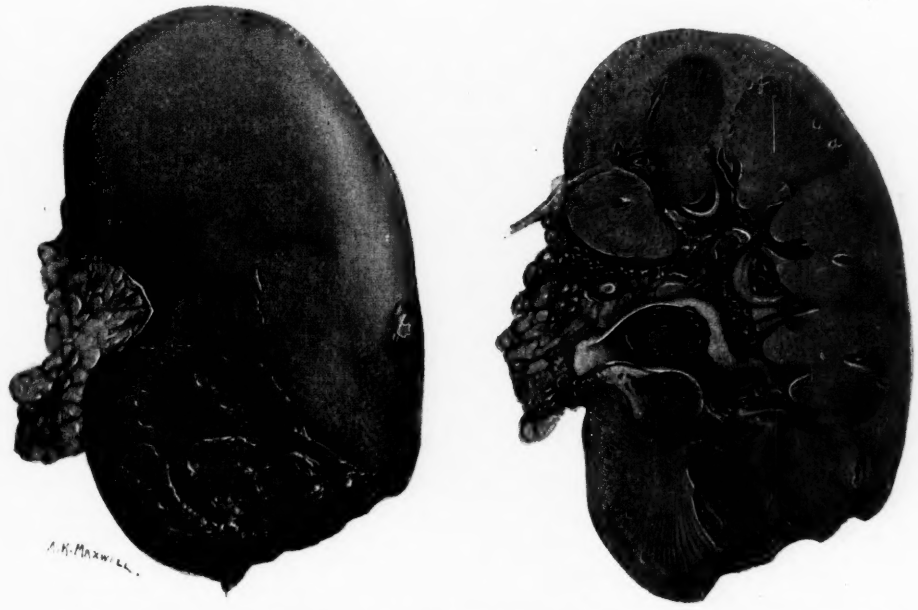

Fig. 190.—Recent shell wound of lower pole of kidney. The patient died from other wounds a few hours after being hit. The cavity of the wound is filled with blood-clot and disintegrated kidney substance. Lacerated masses of renal tissue fungate through the torn capsule. Columns of blood infiltrate the cracks, fissures, and loose areolar spaces leading towards the uninjured parts of the organ. The pelvis is filled with blood-clot.

nature and size of the missile, and, no doubt, on the range of fire. Many of the wounds of the parenchyma doubtless involve the infundibula and calices, but escape of urine is not likely to take place unless the wound is large and has extended into the pelvis of the kidney itself. If urine escapes from the external wound, the inference is that the pelvis or ureter has been injured. The effects of the missile on the structure of the kidney will be more fully dealt with later.

Wounds of the Ureter.—Wounds of the ureter have not been very frequent at the base. In most cases one would expect these to be but a small part of more severe injuries involving intestine, blood-vessels, etc. The feature of these wounds is the escape of urine externally, and they will be dealt with under the heading of Urinary Fistula.

EFFECTS OF THE MISSILE ON THE KIDNEY.

The effects produced by a missile on the kidney will depend on (1) the direct damage caused by the missile; (2) the damage due to interference with the vascular supply; (3) the damage resulting from pressure of hæmorrhage; and (4) the results of sepsis.

Macroscopic Appearances.—If a fresh wound of the kidney be examined (*Fig.* 190), the following appearances will be found. The cavity or track of the wound is filled with blood-clot and disintegrated kidney substance. Lacerated masses of renal tissue fungate through the torn capsule. Columns of blood infiltrate the cracks, fissures, and loose areolar spaces leading towards the uninjured parts of the organ. The pelvis contains blood-clot. Occasionally, one finds small subcapsular hæmorrhages, or a few points of ecchymosis in parts remote from the injury.

FIG. 191.—*Case* 30. Showing perforating wound of kidney, surrounded by an area of necrosis, and an area of necrosis in cortex. Twelve days after injury. *a*. Perforating wound.

If a wound of the kidney is examined some days after the injury, certain vascular effects will have become manifest:—

1. The missile in its passage may have damaged one or more of the arteries lying in the intervals between the pyramids. In this case the territory supplied by these vessels will have undergone necrosis, and will stand out from the rest of the kidney as yellowish-white areas. This is well shown in *Figs.* 191, 192.

2. Thrombosis extending from the neighbourhood of the wound may have interfered with the vascular supply of the contiguous portion of the organ. This will be apparent as a ring of yellowish-white colour surrounding the margins of the wound, contrasting strongly with the neighbouring healthy portion (*Figs.* 191, 193, and 195).

3. The pressure of the extravasated blood may have produced nutritional changes in the adjoining kidney-substance. In this case there is a tendency to recovery as the blood-clot becomes absorbed.

4. Portions of the fungating kidney-substance in the wound itself will have become necrotic (*Fig.* 193). If sepsis is present, inflammatory changes

in the kidney and its pelvis will be added. The fungating masses will be covered with greyish sloughs (*Fig.* 193), during the separation of which secondary hæmorrhage may take place.

TYPES OF INJURY.—The types of injury to the kidney with which we are familiar as the result of our present experience may be classified as follows :—

1. *Injury to a branch of the renal artery without direct involvement of the kidney itself.*—We were fortunate in obtaining a specimen in which a large branch had been injured without immediately fatal results. In this case (*Case* 31), a large branch of the renal artery going to the lower pole was divided. The patient died from a concomitant injury to his spine, ten days after the wound was inflicted. The whole of the area supplied by the injured branch underwent necrosis. A beautiful drawing of the kidney was made by Sergeant Maxwell (*Fig.* 194). It will be seen that the greater part of the lower pole has died. Surrounding the necrotic area is a narrow red zone indicating the line of demarcation between the dead and living tissue. The patient had suffered from moderate hæmaturia.

FIG. 192.—Kidney in section from same case as *Fig.* 191. Note the perforating wound filled with blood-clot and disintegrated kidney substance, and the area of necrosis due to involvement of a branch of the artery. Twelve days after injury. *a.* Perforating wound.

The kidney differs from the lung and liver in not possessing a collateral circulation. Hence, the rapid absorption and disappearance of infarcts, which is a feature in injuries to the blood-vessels of the lung and liver, is not likely to occur in the kidney. The final result in the above case, presuming that the patient had recovered and the wound had remained aseptic, would probably have been a large scar replacing the necrosed area.

2. *Contusion of the kidney, produced by the passage of a missile in the vicinity without actual contact with the organ.*—In *Case* 37, a large fragment of shell entered the back to the left of the spine, just below the outer end of the last rib. *X* rays showed the fragment lying in the spinal canal between the 2nd and 3rd lumbar vertebræ. Laminectomy was performed,

and the fragment was removed from the site indicated in the skiagram. The track of the missile, which had crossed the region of the kidney, was investigated, but there was no evidence of direct injury to that organ. The patient had suffered from hæmaturia from the day of his injury. In *Case* 7, a piece of shell had entered in the right posterior axillary line, and had passed across the middle line, finally lodging in the left half of the theca between the 11th and 12th dorsal vertebræ. Post mortem, a hæmatoma was found at the upper pole of the right kidney, between the capsule and the kidney substance, and there was ecchymosis of the upper pole below the hæmatoma. The piece of shell did not strike the kidney itself. Colonel Wallace, in the Lettsomian Lectures for 1917, draws attention to a case in which many cracks were produced in the capsule by shell fragments which did not touch the organ itself.

3. *Perforating wounds of the kidney.*—These are produced by bullets or fragments of metal. Both entrance and exit wounds may be small, or the exit wound may be pyramidal in shape and larger than the entrance wound. *Figs.* 191 and 192 illustrate this type of wound.

4. *Tangential wounds.*—A good example of these is seen in *Fig.* 195, taken from *Case* 14. A furrow has been ploughed obliquely in the posterior surface of the kidney by a small piece of shell which is seen resting near the upper pole. Surrounding the track is the area of necrosis to which attention has already been drawn.

5. *Wounds destroying one or other pole of a large area of the kidney.*—In *Case* 42, as may be seen in *Fig.* 193, a large bite has been taken from the middle of the outer border of the organ. There was a large suppurating hæmatoma around the kidney. The patient died thirteen days after being wounded, and the vascular effects of his injury are apparent in the necrotic area surrounding the wound, and in the fungating kidney-substance in the wound itself.

In *Case* 41, in which the kidney was removed for secondary hæmorrhage fourteen days after injury, the following appearances were seen. There was a large mass of fungating tissue on the convexity of the lower pole. The central part of this pole was occupied by irregular lacerated and necrotic patches. Surrounding these parts was a peripheral zone of deep purple subcapsular hæmorrhage. The pelvis of the kidney contained blood-clot. Round the stitch-holes, made at a previous operation at a clearing station, were small irregular patches of necrosis. On section, necrosis seemed to be limited to the cortex. In some places hæmorrhage extended along the pyramids towards the papillæ, but the structure of the pyramids, though they were deeply engorged, was apparently intact. The remainder of the kidney was pale, but otherwise apparently normal.

6. *Extensive destruction of the kidney.*—Cases with extensive destruction are frequently seen at the clearing stations, where the damaged organ is usually removed. In some the kidney is broken into many fragments; or less extensive injuries, such as large fissures or irregular star-shaped wounds, may be present. In *Case* 26, the organ was found completely divided into two portions. An almost similar condition was found in *Case* 2.

Microscopical Appearances. — In the foregoing paragraphs the gross effects of the missile have been described. It remains now to enquire into the effects on the apparently uninjured and, to the naked eye, normal parts of the organ remote from the injury. The effects of injury to vessels upon the area supplied by them has already been mentioned. The effects of the missile on the kidney may be ascertained by microscopical examination, and, to some extent, by clinical investigations on the function of the damaged organ. I propose to deal briefly with the microscopical appearances of sections taken from various parts of injured kidneys, and to mention a case in which both microscopical examination and clinical investigation of the kidney function were carried out. Later, I shall append what clinical evidence I have been able to obtain as to the function of the damaged organ as ascertained by cystoscopy.

FIG. 193.—*Case* 42. Large lacerated wound of kidney. Note surrounding area of necrosis, and masses of fungating kidney substance becoming necrotic. Thirteen days after injury.

Sir Anthony Bowlby,[1] in the Bradshaw Lecture for 1915, expresses the opinion that, even in apparently trivial wounds, the damage to the kidney may be more extensive than the naked-eye appearances would lead one to suspect. In support of this he quotes a case in which microscopical examination of sections, made by Captains Stokes and McNee from parts of the kidney distant from the obvious injury, showed extensive disorganization.

Captain E. F. Bashford,[2] referring to the case in question, cannot agree with the interpretation of the appearances seen in the figure accompanying the description, and details the microscopical anatomy of two other cases of recent injury, and supplies descriptive figures. From a study of the sections in these cases, he comes to the conclusion that the injury to the kidney in both was of a strictly local character.

Microscopical examination seems, in three at least of the four cases about to be mentioned, to confirm Captain Bashford's views as to the limited nature of the injury produced by certain wounds of the kidney. In the fourth case, it is difficult to say how far local and general sepsis was responsible for the changes present in the sections from the remoter parts of the organ.

In *Case* 30 (*see Figs.* 191 and 192), a piece of shell had passed through the lower pole of the kidney. The track of the missile was dark-red in colour, and was surrounded by a narrow zone of yellowish-white colour in the fresh specimen. In addition, there was a pyramidal zone of necrosis of the extent shown in the drawing. Portions of the kidney were sent to Dr. J. A. Murray,

FIG. 194.—*Case* 31. Injury to a large branch of the renal artery, followed by necrosis of the lower pole of the kidney. A portion of the fleshy infiltrated perirenal tissue is shown. Fifteen days after injury. *a*. Branch of renal artery ; *b*. Branch of renal vein.

of the Imperial Cancer Research Fund, who kindly furnished microscopical sections, which were examined by him and by Captain Herbert Henry. Dr. Murray reports :—

In this case there is a good deal of hæmorrhage around the injury, and widespread fatty degeneration of the kidney tubules. The interstitial connective tissue is increased throughout, but this is so uniform that it may have been an antecedent condition.

Captain Henry confirms this opinion, and also reports that the kidney sections at a distance from the injury show a normal structure. Cystoscopic

examination had previously revealed blood but no pus in the specimen taken by ureteral catheter from the affected side, and normal urine of good specific gravity from the uninjured side.

In *Case* 32, the kidney showed near the centre a small perforating wound produced by a fragment of shell, almost exactly similar to the wound in the last case. Sections were made by Dr. J. A. Murray, who reports as follows :—

In this case the processes of repair are more advanced [than in *Case* 30]. There is considerable formation of granulation tissue under the organizing blood-clot. The epithelium of the tubules shows very little fatty change. In the region of the wound only is there much alteration, and some of those tubules contain masses of fibrin filaments, indicating the previous existence of hæmorrhage. I should imagine that the second case is of longer standing than the first, but do not care to express a definite opinion without the clinical notes.

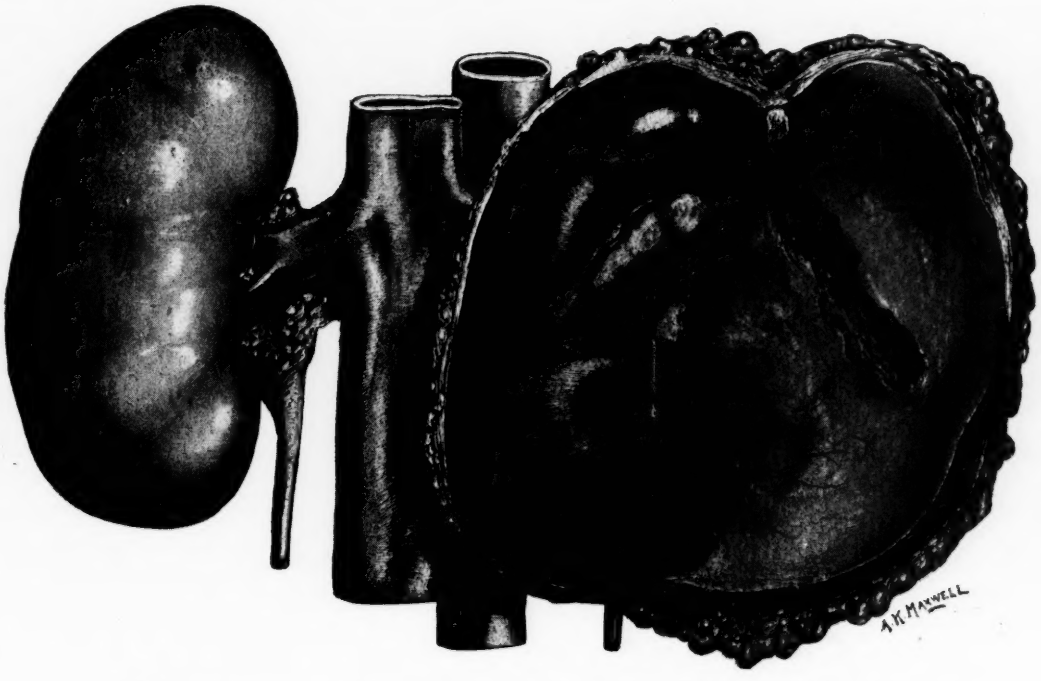

FIG. 195.—*Case* 14. Tangential wound of kidney. The piece of shell is seen at the upper pole. Patches of necrosis bordering on track. Some infiltration of perirenal tissues. Twenty-four days after injury. The perirenal tissue has been reflected from the posterior surface of the kidney.

This opinion is correct. In the previous case (*Case* 30) the kidney was removed twelve days after injury, while in *Case* 32 nephrectomy was performed one month after injury. The microscopical sections of the latter case were also examined by Captain Henry, who agrees with the interpretation of Dr. Murray.

In *Case* 24, I have received microscopical sections from Major McEwen which he has kindly prepared for me from the kidney, removed by him for

secondary hæmorrhage on the seventh day after the injury. The injury to the kidney was more severe than those we have been considering, but the case may with advantage be mentioned here. A large ragged wound, produced by a shell fragment, was found extending from the cortex into the pelvis of the kidney. Portions were taken for microscopical examination (*a*) from the wounded area and parts of the organ immediately adjacent; (*b*) from an area of necrosis in the cortex; and (*c*) from a part of the kidney distant from the wound. Captain Henry kindly examined the sections, and reported as follows:—

a. Purulent infiltration in parts, with large giant phagocytic cells containing destroyed blood-pigment; skeleton only of kidney tissue left in one set of slides, the capillaries and intertubular spaces being filled with active polymorph cells; attempts at regeneration in certain tubules, and marked fibroplastic reactive changes. Summary: The area of damaged kidney tissue shows: (1) Destruction of parenchyma in various stages, with purulent infiltration; and (2) Reactive changes, consisting chiefly of fibroplastic healing, and, to a much slighter extent, attempted regeneration.

b. Infarcted kidney, avascular and with no reactive changes, badly staining.

c. Apparently normal kidney.

In *Case* 14, already referred to, in which the missile had grooved the posterior surface of the kidney, microscopical sections were made by Captain Hopwood from various parts of the injured kidney and also from the uninjured one. Captain Hopwood's report is as follows:—

In the track of the missile.—There is hyperæmia, hæmorrhage, necrosis of kidney cells in varying stages, and round-celled infiltration.

In the yellowish-white patches bordering on the wound.—There is hyperæmia, hæmorrhage, and total necrosis, including tubules and glomeruli. Even in the glomeruli, all nuclei have disappeared. In the other parts, round-celled infiltration and definite casts, as the result of hæmorrhage, are seen.

In the area of the kidney distant from the track.—Parenchymatous degeneration and necrotic parts are found in the tubules rather than in the glomeruli. Tubular epithelium degenerated. Crystals of hæmatin.

In the uninjured kidney.—Some hæmorrhage into and around tubules. None in glomeruli. Some degeneration of renal cells.

The clinical evidence, as ascertained by cystoscopy, is as follows: On the uninjured side the urine had a specific gravity of 1020, and contained albumin, but no pus and no casts. On the affected side the urine had a specific gravity of 1005, and contained blood, much albumin, cellular detritus, and pus cells in quantity.

It is probable that the degenerative changes common to both kidneys in this case were the result of sepsis and fever, and such as might be occasioned by any septic wound unconnected with the kidney. It is also probable that some of the changes in the affected kidney were not unconnected with local sepsis in that organ. Cystoscopy was carried out sixteen days after receipt of the injury, and about a week before the patient's unexpected death from intraperitoneal hæmorrhage.

CYSTOSCOPY.

In this section is shown what attempts have been made by ureteral catheterization and colour tests to estimate the effect produced on the kidney function by such wounds as we have been considering.

It will be seen from the table that all the cases have been examined at least some days after injury. The *immediate* effect on the function of the kidney is not dealt with here. I have not been able to see the cases sufficiently early to be able to say whether secretion is temporarily abolished, as has been suggested by surgeons working at the clearing hospitals.

Cystoscopy may be resorted to in cases of injury to the kidney and ureter with the following objects in view: (1) To determine the effect of a wound on the function of the injured kidney. (2) To determine the presence and condition of the kidney of the opposite side. (3) To determine whether the injury is confined to one kidney, and if so, which; cases have occurred in which both kidneys have been wounded by a missile passing transversely. (4) To determine the extent of the injury in wounds of the ureter. (5) To determine by the aid of the ureteral catheter, combined with radiography, the position of retained missiles relative to the kidney or ureter.

Cystoscopy was carried out in 14 cases of this series. The cases investigated as regards the function of the damaged organ may be divided into the following classes (see Table, p. 260):—

1. *Those in which rapid recovery took place.*—In *Case* 8, the bullet was proved by operation to have passed through the kidney near the hilum. The urine, which contained blood on the patient's admission to hospital, was normal eight days after injury. The specific gravity of the urine from each kidney was 1015, and each specimen was free from blood, pus, and albumin.

In *Case* 12, a bullet had apparently passed through the kidney. Three weeks later the affected kidney was functioning as well as its fellow of the opposite side. Indigo-carmine appeared in equal quantities, and at the same moment, on both sides. There was a trace of albumin in both specimens, but as many of these patients run a moderate temperature, probably from sepsis, too much importance need not be attached to this.

2. *Those in which disturbance of function was indicated by a diminished specific gravity on the affected side.*—For many years I have attached much importance to the estimation of the relative specific gravities of the urine from each side in kidney cases.[3] I have found that in the unilateral affections of the kidney common in surgical practice, a diminution of the specific gravity in the urine from the affected kidney is of very usual occurrence. In tubercle of the kidney,[4] for instance, in both early and late cases, this sign is hardly ever absent; it does not necessarily mean a seriously diseased organ, as it occurs so early that very little damage has as yet been done to the kidney. It also occurs in some, but not all, cases of renal calculus. Even a small stone may produce it. Some years ago[3] I removed an oxalate stone weighing eight grains from the pelvis of the kidney of a young lady. The specific gravity of the urine on the affected side was 1005, as against 1015 on the opposite side. I have had many such cases since. In that just mentioned, and in similar cases on which I have since operated, there was no evidence whatever

of any but the most trivial and temporary damage to the kidney. In tumours of the kidney[5] this sign is also often present, even when the growth is comparatively small and much healthy kidney substance is present. In pyelonephritis, pyonephrosis, and hydronephrosis, the specific gravity of the urine on the affected side is likely to be low, but here extensive disease is present. In some cases the diminished specific gravity is due to reflex unilateral diuresis from irritation. This is particularly the case with small irritating calculi. There is often in these cases obvious increase in the rate of flow from the ureter of the affected side. In other cases the diminished specific gravity appears to be due to inability of the kidney to separate the solid constituents of the urine from the blood in normal quantity.

In cases of injury to the kidney I have not been struck with any decided increase in the vigour or rate of the ureteral jets; in some, indeed, the flow has been less in quantity and the jets have been more sluggish than normal. A diminished specific gravity on the side of the injury was present in the following cases of the present series. In *Case* 4, it was 1016 on the affected side, as against 1022 on the sound side; in *Case* 11, it was 1005 as against 1010; in *Case* 13, 1015 as against 1025; in *Case* 14, 1005 as against 1020; in *Case* 19, 1015 as against 1020; and in *Case* 39, 1005 as against 1010. These cases are obviously too few in number from which to draw definite conclusions, but they are sufficiently striking to suggest a line of investigation in connection with the subject under discussion.

3. *Those in which disturbance of function was indicated by some alteration in the permeability of the kidney to dyes, such as indigo-carmine.*—Disturbance of function, as ascertained by colour tests, was sometimes found in cases in which the specific-gravity tests had given negative results. In these observations I have used indigo-carmine, in 2-grain doses, mixed with 2 drachms of sterile water. The mixture is injected deeply into the flank or buttock at the same time as catheters are introduced into the ureteral orifices. The time of appearance of the first trace of colour in the jets from the catheters is noted. Unfortunately it was not possible to continue the examination for long in many cases, owing to pressure of work in the theatre, but the results, incomplete as they are, are given for what they are worth.

In *Case* 11, besides a reduced specific gravity on the affected side, the blue colour of the indigo-carmine was less deep on that side. The colour was apparent on both sides fifteen minutes after injection, but throughout the observation it was of a lighter hue on the affected side.

In *Case* 13, both the specific gravity and the depth of colour were diminished on the affected side. The colour was apparent in both specimens twelve minutes after injection.

In *Case* 34, the specific gravity was 1015 on both sides, but the colour took twenty-five minutes to appear on the affected side, as against twenty minutes on the sound side. This patient had passed through a severe illness, with fever and jaundice.

In *Case* 35—probably only a slight contusion of the kidney—the specific gravity was equal on both sides, and the colour appeared in both specimens in ten minutes. The colour was a little deeper, however, on the affected side.

In *Case* 39—a shrapnel ball injury—the colour was deeper on the affected

side. It came through on both sides in eighteen minutes, with the patient under ether. In this case a deeper colour was associated with a diminished specific gravity on the injured side.

The significance of these findings may perhaps be better appreciated after a reference to a recent paper by Tremolières and Caussade on " Nephritis Aiguës de Guerre,"[6] in which the authors give the results of their observations on the use of indigo-carmine as a test of renal permeability. They state that this dye appears in the urine twenty minutes after injection; after half an hour the colour is intense and at its maximum; from this time on the colour decreases regularly, until in six or seven hours the urine is again normal in colour. Exaggeration, diminution, or irregularity of elimination indicates pathological renal permeability. The authors divide acute war nephritis into two main groups :—

Group A: Cases with insidious onset, which on arrival at a hospital in the interior reserved for nephritis cases, showed albuminuria only, with no other clinical signs of nephritis. These cases had normal kidney function, including a normal elimination of indigo-carmine.

Group B: Cases with acute onset, which on arrival at the hospital showed, besides albuminuria, other signs of kidney trouble, such as hæmaturia, œdema, etc. These cases were subdivided into two types. The first included cases showing *increased* permeability to indigo-carmine, with retention of chlorides. The second type included cases of a more severe character, showing not only retention of chlorides, but also of urea; in these there was *decreased* permeability to indigo-carmine.

The cases I have so far examined have been, as I have stated, too few to draw conclusions from. In the light of the work of the authors just quoted, it may be that in those in which the permeability was greater on the injured side, the kidney had suffered less severe damage than in those in which the permeability was diminished. My own experience with indigo-carmine in civil and military surgery has been that the dye comes through in rather shorter time than that stated by these authors. I frequently find it in the urine in from ten to fifteen minutes after injection under ordinary circumstances in a normal subject. General anæsthesia seems to delay its appearance.

4. *Those in which abnormal constituents—such as blood, pus, albumin, and micro-organisms—have been found in the urine from the affected side.*—Albumin may be present on both sides in a patient suffering from sepsis, and is therefore only important from our present point of view when there is a greater amount on the affected side. A few blood cells are present so commonly as the result of even the most careful ureteral catheterization, that unless the number is large, no importance can be attached to them. If cystitis is present, a few pus cells may gain access to the catheter during its passage through the bladder, and this must be taken into consideration in judging of the condition of the kidney. Finally, contamination with micro-organisms is very likely to occur during the most careful cystoscopy. I always use ureteral catheters that will stand boiling; but the cystoscope is hard to sterilize.

Comparison of the findings on both sides, however, will give results

TABLE OF CASES IN WHICH THE FUNCTIONAL CAPACITY OF THE INJURED KIDNEY WAS INVESTIGATED.

Case	Nature of Injury	Length of Time since Injury	Specific Gravity		Indigo-carmine	Chief Abnormal Constituents on Injured Side
			Affected Side	Sound Side		
4	Injury to pelvis and cortex	Two months	*1016*	*1022*	—	Blood, pus, micro-organisms, epithelial casts
8	Perforating wound	Eleven days	1015	1015	—	Nil
11	Tangential wound (?)	Three weeks	*1005*	*1010*	Deeper colour on sound side	Nothing definite
12	Perforating wound	Three weeks	1005	1005	Same depth of colour on both sides	Streptococci and *B. coli*
13	Perforating wound	Four weeks	*1015*	*1025*	Deeper colour on sound side	Pus and streptococci
14	Tangential wound	Sixteen days	*1005*	*1020*	—	Blood, pus, streptococci
17	Tangential wound	Twelve days	1015	1015	Deeper colour on sound side	Blood
19	Perforating wound	Seven days	*1015*	*1020*	—	Blood
34	Tangential wound	Twenty-four days	1015	1015	Delayed on affected side	Nothing definite
35	Contusion	Seventeen days	1020	1020	Deeper colour on affected side	Nothing definite
36	Perforating wound	Three months	1010	1010	Same depth of colour on both sides	Nil
39	Perforating wound	Three weeks	*1005*	*1010*	Deeper colour on affected side	Albumin, pus, streptococci

of value. In *Case* 4, there were a few pus cells, numerous red cells, some epithelial cells, *B. proteus*, and Gram-positive cocci on the affected side. In *Case* 13, pus, streptococci, and cells from the renal pelvis were found on the affected side. In *Case* 14, blood, pus, streptococci, and cellular detritus were found on the injured side. In *Case* 17, blood, but no pus, was found on the affected side. In *Case* 30, blood, but no pus, was obtained from the injured side. In *Case* 39, pus cells and streptococci in considerable numbers were found on the affected side.

THE VALUE OF X-RAY EXAMINATION IN KIDNEY INJURIES.

In all our cases of kidney injury arriving at the base with retained foreign bodies, we have had stereoscopic radiograms taken. These have been of the greatest service in accurately locating the foreign bodies, and in enabling us to form an idea as to their course and the structures likely to have been injured during their passage. Mackenzie Davidson's method of localization has been used, and has proved accurate and reliable. Most of the cases here referred to have been *x*-rayed by Captain Gamlen; but Major Higham Cooper, Major Curtis Webb, and other radiographers have also given me valuable assistance; I am much indebted to these officers for their kind co-operation. In addition to the ordinary methods of localization, I have in several cases used the opaque ureteral catheter, passed into the pelvis of the kidney, combined with stereoscopic radiography, when the missile was thought to be in the vicinity of the kidney or ureter. In this way it has been possible to estimate with great exactitude the position of the foreign body relative to the kidney or ureter. I have, in a previous communication,[7] described this method, and given details of cases so examined. The following in the present series were investigated in this way.

In *Case* 8, already published,[7] a bullet was seen to be lying in the vicinity of the kidney. An opaque ureteral catheter was passed into the uppermost calyx. Stereoscopic radiograms were now taken. The base of the bullet was localized as lying in the line of the ureteric catheter and 1·8 cm. behind it. The apex pointed downwards and outwards, and was almost 2 cm. further away from the plane of the catheter. The bullet lay 5·7 cm. below the point of the catheter. With these measurements, we arrived at the conclusion that the foreign body was just outside the kidney, near the lower pole. Operation proved the correctness of this assumption.

In *Case* 19, two pieces of shell were seen lying anterior to the plane of the upper part of the ureteral catheter. The upper fragment was localized as lying 3·8 cm. anterior to the plane of the catheter, and therefore well in front of the kidney, probably in the liver. The lower fragment was localized as lying 2·2 cm. anterior to the plane of the catheter, and therefore probably just in front of the kidney. The patient was transferred to England without any attempt being made to remove the foreign bodies. He remains, a year after his injury, free from urinary symptoms. It is interesting to note that in the report made on his case in England, where he was again *x*-rayed, the fragments are assumed to be *in* the kidney.

In *Case* 14, the foreign body, a fragment of shell (see *Fig.* 195), was

localized as lying in the same plane as the ureteral catheter, on a level with its point, but nearer to the middle line of the body, probably at the inner margin of the upper pole of the kidney. Post mortem, it was found exactly in this position.

In *Case* 35, two fragments of metal were localized as lying 4 cm. and 1·9 cm., respectively, posterior to the plane of the ureteral catheter. They had entered from behind, and had caused slight contusion of the kidney, probably without actually touching it. The foreign bodies were not removed.

When we come to discuss urinary fistula, we shall see that use may be made of radiography to demonstrate the patency or otherwise of an injured ureter. *Case* 27 was investigated in this way, and will be described in due course.

RECONSTRUCTION OF THE TRACK OF THE MISSILE.

In most of the cases mentioned in this communication, an attempt has been made by sectional anatomy to reconstruct the track of the missile. It has been assumed that the foreign body generally takes a straight course. This assumption cannot be defended in all cases, as a missile striking a hard surface may be deflected. In these cases, a line drawn from the entrance wound to the point of deflection—a fractured bone, for instance—and from the point of deflection to the position of the foreign body or the exit wound, will indicate, as a rule, the course taken. Here *x* rays will afford valuable help.

When the foreign body has been localized by *x* rays, certain fallacies must be avoided. For instance, when a missile has entered a hollow viscus and passed on, it would be obviously absurd to imagine a straight course from the entrance wound to the position of the foreign body as localized by *x* rays. Similarly, where the missile has fallen into the peritoneal cavity, as in *Case* 18, a line drawn from the entrance wound to the position of the foreign body might be far removed from the track of the missile. It has also been objected that the line of the track varies according to the position of the wounded man at the time of receipt of the injury, and this must be admitted.

On the other hand, in connection with the area of the trunk now under consideration, the surgeon will gain valuable and interesting information, which will help him in dealing with the case, if he reconstructs the track on the assumption that a more or less straight course has been taken. Captain P. T. Crymble,[8] who first suggested the use of cross-sections for this purpose, has demonstrated that in many of his cases reconstruction of the track by him gave results not far removed from the true state of affairs as ascertained post mortem or by operation, and my own experience bears this out.

In transverse wounds in the lumbar region, one can, as in *Case* 6, determine with some prospect of accuracy which kidney is likely to have been wounded. The missile in this case, if it had taken a straight course between the entrance and exit wounds, would have missed the left kidney and have injured the right. In a case of severe hæmaturia without external hæmorrhage, the probability of the offending kidney being thus indicated would be of great service, failing cystoscopy, should operative measures be necessary. Notwithstanding all

that has been urged against the method, those who have used it are satisfied that in no other way can such useful information be obtained. The objections that all bodies are not alike, and that certain patients may be abnormal, do not, in my opinion, weigh against the obvious advantages.

For my own purposes I use a cross-section atlas of anatomy. A key figure shows the body divided into sections of a certain thickness. Each of these slabs is numbered, and at the corresponding number in the atlas the organs

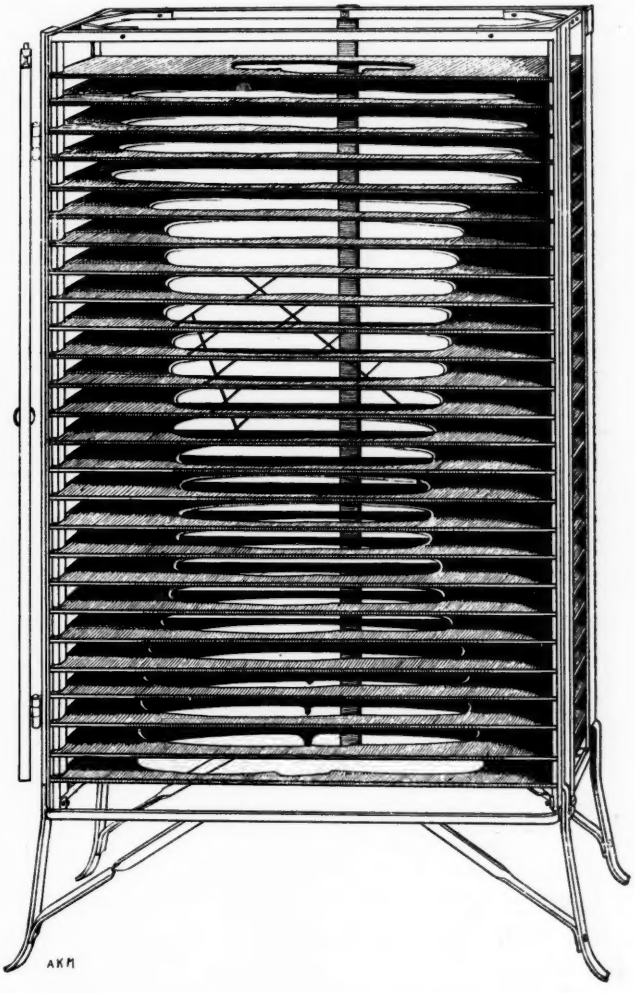

FIG. 196.—Diagram representing the frame described in the text. Each shelf corresponds to a plate in a cross-section atlas of anatomy, and the aperture fits the outline of the section at that level.

Two tracks of missiles are shown. The point where the line of the track passes through the space in each shelf is determined by passing a thread or wire across the space, and marking the spot where it is intersected by the line representing the track, as shown in *Fig.* 197, where the point of intersection lies in the kidney.

and structures are figured as they are found at that level. For use with this atlas I have had a frame with shelves made (*Fig.* 196). The frame supports the shelves, which are so arranged that each shelf corresponds to the upper surface of a section of the body at that level. Instead of each shelf having printed on its surface a drawing of the structures seen at this level, it has a large opening which just fits the drawing in the atlas. The circular opening, therefore, of this shelf corresponds to the contour of the body at that level.

When the shelves are placed in position in the frame, and one looks from above down, a hollow space like a mould of the body is seen, and a thread may be arranged so as to stretch from the point of entrance to the point of exit or to the location of a foreign body, anywhere in the hollow space. The foreign body may be slung in the proper position by threads or wires. The point at which the thread representing the track passes through the circular aperture in each shelf can easily be shown by cross-threads, with an ink mark at the points where they are intersected by the thread representing the track. If this is done in each segment, and the shelves are placed in turn so as to fit the plates

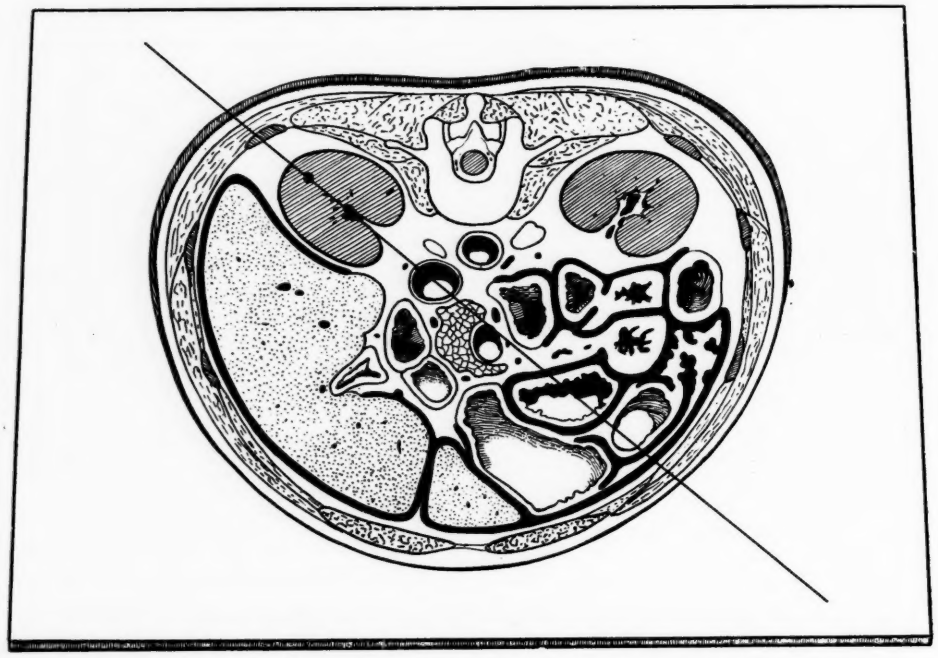

FIG. 197.—Diagram showing one of the shelves removed from the frame seen in *Fig.* 196, and fitted on to a cross-section in the lumbar region.

The line on which is marked the point where the track passes through the space need not be oblique as represented in the drawing, but may be made in any direction so long as it touches the line of the track.

in the atlas, the organs or structures penetrated will be seen at a glance (*Fig.* 197). This has proved to be a very convenient method of reconstructing the track.

Looking over the notes of the cases appended, it will be seen that the most usual route of approach of a missile to the kidney is posterior or postero-lateral, just below the ribs; the route through the chest wall comes next in order of frequency; transverse wounds come third; while, at any rate in the cases seen at the base, the route from before back through the abdominal cavity is the least frequent.

ASSOCIATED INJURIES.

In the cases seen at the base, the most frequent associated injury has been a wound of the *pleural cavity.* In 17 out of 42 cases (40 per cent), the missile reached the kidney by way of this cavity. In 7 cases hæmothorax was definitely diagnosed; in 3 an empyema formed; in 1 hæmoptysis was present; and in the remaining cases the missile was presumed to have passed through the pleural cavity from a study of the anatomy of the track.

The *liver* is very frequently injured in wounds involving the right kidney. In 14 cases (33 per cent) the missile had probably passed through or injured the liver, and 2 of these developed an abscess around a retained foreign body. In most cases the track through the liver gave rise to no urgent symptoms during the patient's sojourn in France.

The *spleen* has fairly frequently been found damaged in injuries of the left kidney treated at the clearing stations. In only 1 case of the present series was this complication found.

The *spine* is injured in a fair proportion of cases. In 6 out of our series of 42 (14 per cent) there was definite evidence of associated spinal injury, and in 3 additional cases injury of the bones, but not of the cord, was suspected.

The *hollow viscera* were injured in 5 cases, as ascertained by operation: the colon in 3; the small intestine in 1; and the duodenum in 1.

The *pancreas* was found injured in 1 case.

The *diaphragm* is perforated in those cases in which the missile passes through the pleural cavity on its way to the kidney. In most of the cases seen at the base no treatment of this structure has been required.

The *peritoneal cavity* may be entered by the missile without obvious damage to hollow viscera, as in *Case* 18, in which the bullet was found free, and in *Case* 23, in which there was an aperture through which the missile had disappeared after crossing the line of the ureter.

SIGNS AND SYMPTOMS.

The signs and symptoms of injured kidney are as follows:—

Hæmaturia, which may be microscopic, moderate, or profuse. It is well in a doubtful case to ascertain that the blood is not coming from the bladder, as is so frequent in associated injuries to the spine with hæmorrhagic cystitis. I have seen splashes of hæmorrhage scattered over the bladder wall in a case in which a piece of shell had injured one of the lumbar vertebræ without involving the cord; until cystoscopy had revealed hæmorrhage into the mucous membrane of the bladder, the case was thought to be one of injury to the kidney or ureter. It is well also to bear in mind the possibility of hæmorrhagic cystitis unassociated with spinal injury, as I have seen several examples in unwounded men coming down from the front. Other causes of hæmaturia independent of injury will, of course, suggest themselves to the surgeon.

Urinary fistula will be dealt with later. In some cases a watery discharge from the wound has been mistaken for urine. A little care is sufficient to

prevent such an error. It is well to test such fluid with litmus paper, and to examine for the characteristic urinous odour from the dressings.

In addition to these special signs indicating renal or ureteric injury, the following are often present :—

Shock is frequently met with, and may be due to accompanying injury to the abdominal viscera, thorax, or spine.

Anæmia after profuse loss of blood is often very marked in a patient when he reaches the clearing station or the base.

Vomiting was reported in about 25 per cent of the cases. It may have been more frequent. It occurs in uncomplicated cases, but is much more likely to be present when the abdominal viscera have also been injured.

Tenderness and rigidity of the abdominal wall are present in most but not all of the cases. These symptoms may be due to injury of the peritoneum, injury to the abdominal viscera, injury to the pleura and diaphragm, blood in the peritoneal cavity, or retroperitoneal hæmatomata. In some of the reports sent down with the patients from the clearing stations, the definite statement has been made that on arrival there, tenderness and rigidity have been absent.

Abdominal distention is frequently met with, as might be expected. In those cases associated with spinal injury it is very likely to be present.

Dullness in the flanks has occasionally been seen.

A tumour in the flank, due to perirenal extravasation of blood, is sometimes palpable. This may be a sign of importance in certain transverse wounds in which it is not easy to locate the kidney affected.

Fever may be present, and is due to the fact that many of the wounds are septic.

DIAGNOSIS.

The diagnosis of a wound of the kidney or ureter will be made by attention to the signs and symptoms just enumerated In *Cases* 22 and 30, injury to the kidney was quite unsuspected until the occurrence of secondary hæmorrhage—in *Case* 22 into the retroperitoneal tissues, and in *Case* 30 into the bladder. For this reason it is well, in all wounds of the loin, to examine the urine with the microscope for the presence of blood. In some cases the diagnosis of injury to the kidney has been made during an operation in the loin region, or in the course of laparotomy for injury to the abdominal organs. In these cases the actual damage to the kidney has been seen or felt. Attention may be drawn to the fact that an apparently trivial wound in the loin may have involved the kidney. I have seen a piece of shell in the kidney of a patient who died from other causes, and in whom the kidney was never suspected during life.

COMPLICATIONS.

The three great complications of injuries to the kidney and ureter are *sepsis*, *secondary hæmorrhage*, and *urinary fistula*, referred to in detail below. The following are also sometimes present :—

Retention of Urine.—This was present in 8 cases, in 6 of which it was due to associated spinal injury.

Cystitis.—This is a frequent complication. It is due to the presence in the bladder of infected blood which has come from the wound in the kidney. In cases associated with spinal injury it is almost certain to occur.

Fæcal Fistula.—This complication was present in 2 cases. In *Case* 15, the fistula soon closed, and the patient, who subsequently had nephrectomy performed for secondary hæmorrhage, made a good recovery. In *Case* 41 also, nephrectomy was performed for secondary hæmorrhage; this patient died a few days later from sepsis. The presence of a fæcal fistula would appear to predispose to secondary hæmorrhage.

Sepsis.—This complication is present in most war wounds. It is likely to occur in kidney wounds for the following reasons:—

1. A large amount of blood is thrown out into the loose perirenal connective tissue. Both blood-clot and loose connective tissue are notoriously favourable to the development of infection, once micro-organisms are introduced.

2. Owing to the absence of collateral circulation in the kidney, a certain amount of gland tissue in the immediate vicinity of the wound dies. This dead tissue forms a suitable medium for the growth of micro-organisms.

3. If the adjoining colon is bruised or damaged, the entrance of intestinal micro-organisms, or fæces, transforms the wound at once into a septic one.

Secondary Hæmorrhage.—Bleeding from a wound of the hilum or of the kidney itself may take place (*a*) into the peritoneal cavity; (*b*) into the perirenal retroperitoneal tissues; (*c*) through the wound in the parietes; and (*d*) into the bladder by way of the ureter.

a. Bleeding into the peritoneal cavity may occur in the early stages, but is not commonly met with at the period when the patient reaches the base.

b. When blood infiltrates the retroperitoneal connective tissue, it often gives rise to a huge mass which, on exploration, looks like a bullock's heart. This mass moves with the kidney during respiration, and sometimes becomes rounded off, so that an operator meeting with it for the first time might mistake it for a greatly enlarged kidney. To reach the kidney it is necessary to peel off this overlying infiltrated fleshy mass.

c. Hæmorrhage is sometimes revealed by bleeding through the external wound, though the urine appears to the naked eye to be clear. This may be due, as Sir George Makins suggests,[9] to a fragment of kidney substance obstructing the ureter, or, more commonly, to blocking of the ureter with blood-clot.

d. In most of the cases of injury to the kidney that I have seen, blood in greater or less quantity has been present in the urine. In wounds confined to the pelvis of the kidney or the ureter, however, this sign may be absent, or at any rate may pass unnoticed by the patient or his medical attendant. In *Case* 30, the first indication of any injury to the kidney was severe hæmaturia twelve days after receipt of the injury. In *Case* 22, there was no history of hæmaturia, but no microscopical search was made for it; a fatal hæmorrhage took place into the retroperitoneal tissues. Many of the patients gave a history of having noticed blood in the urine shortly after

being hit. In others, a note accompanied the patient saying that the specimen removed by catheter at the clearing station contained blood. In the cases in which the urine was microscopically examined at the base, blood was present in almost every one. In addition to blood, pus and micro-organisms were frequently present, even when no catheter had been passed. As has been pointed out, it is well to exclude cystitis as a possible cause of hæmaturia. In *Case* 31, though a vessel at the hilum was alone injured, blood was present for nine days after injury. This had completely disappeared on the eleventh day, when a final microscopical examination of the urine was made.

If the blood is poured out into the ureter in large quantity, clotting is likely to take place when the blood reaches the bladder. This will there give rise to difficult micturition, and to hypogastric or penile pain. In addition, cystitis is very likely to follow. The passage of clots or of fragments of kidney down the ureter may give rise to severe renal colic. The amount of blood in the urine varies from a microscopical quantity to a deluge sufficient to blanch the patient. The duration of the hæmaturia in patients who eventually recover without surgical interference varies from a few days to a month or more. During its continuance, there is much variation in the amount of blood passed from day to day. The urine which is deeply tinged one day may be comparatively clear the next. This variation may be due to temporary obstruction of the ureter. If clot is present in the bladder, ureter, or pelvis of the kidney, the urine may be stained though no active bleeding is in progress.

In cases in which the bleeding persists after the tenth or twelfth day, some anxiety will be felt as to the possibility of a large secondary hæmorrhage. In some cases we have been obliged to evacuate our patients to England with blood still present in the urine, and we have not been able in all to ascertain whether complete recovery has taken place or not. In one, nephrectomy for hæmorrhage was performed after the patient had been for some time in a home base hospital.

Secondary hæmorrhage of a severe type took place in 9 cases out of a total of 42 reaching the base. Leaving out of the total 2 cases in which the ureter alone was involved, this gives a secondary-hæmorrhage percentage of 22 in the cases in which the surgeons at the clearing stations felt justified in adopting conservative measures. In some of these the injury appeared to be of quite a trivial nature, as in *Case* 25, in which a simple perforating wound by a bullet was followed by repeated attacks of hæmorrhage, finally requiring nephrectomy. In 8 out of the 9 cases nephrectomy was performed, with 3 deaths; in the ninth case nephrectomy was not considered necessary, and the patient died from other wounds. In *Case* 14, intraperitoneal secondary hæmorrhage took place, and was followed by death; the hæmorrhage was, however, unconnected with the kidney or its vessels.

The date of onset of secondary hæmorrhage in these nine cases was as follows: third day in *Case* 21, seventh day in *Case* 24, tenth to fifteenth day in *Cases* 9, 15, 18, 30, and 41, and four weeks and one month after injury in *Cases* 25 and 32 respectively. In *Case* 9, bleeding took place into the bladder; in *Cases* 18 and 22, into the perirenal tissues; in *Cases* 24, 25,

and 30, into the bladder; and in *Cases* 32 and 41, through the external wound. The nature of the missile was as follows: shell in 6 cases, bullet in 2, and shrapnel ball in 1. Of the 6 cases in which the wound was produced by fragments of shell, 3 died; both cases wounded by bullet recovered; the case wounded by shrapnel ball died from other injuries.

The history of a case of moderate secondary hæmorrhage is well exemplified in *Cases* 15 and 25. In these, several attacks of varying severity occurred, with intervals of freedom; in both cases the surgeon held his hand in the hope that each attack would be the last, and in both cases nephrectomy was finally performed. In the remaining cases, the first or second attack was so severe that radical measures were at once adopted.

From an analysis of the cases I have just mentioned, it is evident that while shell wounds are more likely to cause secondary hæmorrhage, bullet wounds, producing an apparently trivial injury, are not devoid of danger.

Factors Contributing to Secondary Hœmorrhage.—Secondary hæmorrhage in the kidney, as in other parts of the body, is due to failure of the natural processes of repair which tend to arrest bleeding, viz., retraction of the vascular coats, formation of internal and external clot, and final cicatrization of the bleeding vessel or vessels. Here, as elsewhere, the determining factor is the presence of sepsis. There are, however, certain other circumstances which contribute to the risk in the case of the kidney: (1) The blood-supply is out of all proportion to the size of the organ; (2) The blood-pressure is liable to frequent and sudden changes; (3) Collateral circulation being absent, the necrotic areas which form round the track of the missile tend to perpetuate local sepsis.

Treatment of Secondary Hœmorrhage.—It must be admitted that the treatment of secondary hæmorrhage from the kidney or its vessels is highly unsatisfactory. The canon of surgery in other parts is to expose the bleeding vessel and tie both ends in as healthy a spot as available. Even if the vessel in the kidney giving rise to the bleeding could be identified and dealt with, the inevitable necrosis of its area of supply would be a matter of importance, should sepsis extend to it. There seems, up to the present, to have been no middle course between temporizing and ablation of the organ itself. Sir George Makins,[9] in an article dealing with gunshot wounds of the solid abdominal viscera, referring to cases seen by him at the base, says: "In none of these cases was a limited operation justifiable . . . This opinion is founded on the fact that a partial operation is not likely to remove the primary cause of the bleeding, viz., infection. Hence it is not right to expose a patient already grossly anæmic to the risk of a fresh hæmorrhage from a sutured or partially resected organ."

If the surgeon is satisfied that the patient has another sound efficient kidney, his safest course will probably be to remove the offending organ. Is he, however, justified in assuming that such is the case? I have learnt by sad experience in civil practice that even in a healthy-looking patient it is not safe to assume that there is a second competent kidney. Since I came to France, a number of men have been sent down to the base who, on being radiographed, showed renal calculi in one or other kidney. I have seen one case of tuberculous kidney and two cases of pyonephrosis in men otherwise

perfectly fit. I have seen a kidney removed for hæmorrhage, after nephrotomy for stone, and have examined a patient who had but a thin sac remaining of his kidney on one side. With these cases in my mind, and there must be many such in any large body of men, I do not feel justified in recommending removal of a damaged kidney without any knowledge of the state of the opposite one.

For this reason, I would strongly recommend that some attempt should be made, whenever this is possible, even under the adverse conditions of war, to ascertain the condition of the unwounded kidney. An injection of indigo-carmine, followed in a few minutes by examination with an ordinary observation cystoscope, will give information of value to the surgeon, should he be called upon to interfere in a case of hæmorrhage at a later date. Most cases of wounded kidney are sufficiently free from bleeding at one time or another to make this a matter of no great difficulty.

If the bladder is full of clots, the difficulties of cystoscopic examination are almost insuperable. A method which has been carried out by Major Grant Andrew in similar cases in civil practice is well worth a trial. He performs a suprapubic cystotomy, turns out the clots, and examines the interior of the bladder with a Fergusson's vaginal speculum. The jets from the ureters are now seen with the greatest ease. The bladder is subsequently sewn up.

Palpation and radiography may reveal the presence of a second kidney and give some information as to its size and shape, but will not give any idea as to its functional capacity. The method of opening the peritoneum while dealing with the damaged kidney, and passing the hand across to the opposite side to palpate the opposite organ, conveys so little information, and is attended with so much risk in a septic case, that few surgeons would care to adopt it. If, however, an abdominal operation has been performed at a clearing station, such information as can be gained by this method might be noted on the patient's field card. The segregator would be useless in severe hæmaturia. If the bleeding is coming through the wound in the parietes, and clear urine is obtained from the bladder, as in *Case* 41, the inference is that it comes from the uninjured kidney. An examination of such a specimen of urine would give valuable information.

I have carefully examined most of the kidneys removed, with a view to estimating what operation might be carried out short of a total extirpation. In some, the damage was so slight and the condition of the kidney in the neighbourhood of the wound so good, that I feel certain resection of the damaged part might have been attempted—e.g., *Case* 30 (see *Figs.* 191, 192). In one or two cases, the entrance and exit wounds in the trunk and in the kidney itself were so minute and so free from gross sepsis, that no harm could have resulted from a trial of conservative measures, provided that the operation had been performed before the patient had become severely anæmic. The primary cause of the bleeding is infection, but the septic area might be removed entirely, especially in the slighter wounds, by a wedge-shaped excision. It must be remembered, however, that any incision in the kidney may give rise to areas of necrosis from damage to blood-vessels (*Fig.* 198). Much judgement would therefore be required in deciding on a partial operation

in a given case. The fact, however, that partial excision for localized damage to the kidney has been successfully carried out at clearing stations is, I think, an argument in favour of a similar procedure in selected cases at the base. If hæmorrhage comes from a vessel before it enters the hilum, as in the case represented in *Fig.* 194, an attempt might be made to deal with it locally. Such cases will, however, occur so rarely that few surgeons are likely to have experience of the best method of dealing with them.

As to the best time to intervene in a case of secondary hæmorrhage, the condition of the patient and the frequency and severity of the attacks must be the guide. If bleeding is persistent after the tenth day, and of such quantity as to produce anæmia, too much time must not be lost in deciding on operation. If the surgeon elects to give partial nephrectomy a trial, this must be done early, and before the patient is blanched. A very severe attack of hæmorrhage at any period demands instant interference. Transfusion of blood, as in *Case* 32, ought certainly to be carried out if the patient is very anæmic.

In all cases, as soon as the damaged kidney has been dealt with, the bladder must be emptied of clots. We have found that this can be accomplished by a Bigelow's evacuator while the patient is on the table. Suprapubic cystotomy will rarely be required for this purpose.

FIG. 198.—A kidney removed for secondary hæmorrhage three days after nephrotomy for stone. The dots represent suture holes. Such close suturing is unnecessary. Note the areas of necrosis produced by interference with the blood-supply—partly by section and partly by strangulation of blood-vessels by sutures.

As an alternative to indigo-carmine, I have recently been using phenolsulphonephthalein for the investigation of the functional capacity of the kidneys after injury. This is used as follows: One c.c. of a solution containing 6 mgm. of the drug per c.c. is injected intravenously. In one hour, 60 per cent of the total amount injected will be excreted, if the kidneys are healthy. If injected intramuscularly, the time of appearance and the time taken for elimination will be somewhat longer. In acid urine the colour will be a rich amber, in alkaline urine a permanganate pink. To ascertain the amount of the drug present in a given specimen of urine, the latter is made alkaline, and the depth of colour is estimated with a standard solution in a colorimeter. For further particulars the reader is referred to an article on "The Phthalein Test," by Rowntree and Geraghty.[10]

The two cases following, investigated by the phthalein test since this

lecture was delivered, bear so much on several of the points raised, that a short account of them may with advantage be given here.

Sergt. H., was wounded in the left loin by a fragment of shell on June 10, 1917. The fragment was removed from the lower pole of the left kidney at a clearing station. He was admitted to a base hospital under the care of Captain Palmer on June 11. Two days later he developed a urinary fistula, but this was almost dry when he was cystoscoped on June 28, eighteen days after injury. One c.c. of the solution described above was injected into a vein. The drug appeared in the urine from the injured kidney in five minutes, and in that from the uninjured kidney in six minutes. Specimens were collected by ureteral catheters for twenty-five minutes. The specimen from the right, uninjured, side was as follows: Sp. gr. 1005, flow sluggish, phthalein 1 per cent, urea 0·007 gm. per c.c., albumin more than a trace. That from the injured side was as follows: Sp. gr. 1015, flow free, phthalein 4 per cent, urea 0·012 gm. per c.c., albumin a trace. In this case the uninjured kidney showed very doubtful efficiency, and if an operation for secondary hæmorrhage had been required, it would have been unwise to have sacrificed the injured kidney, which appeared from the findings to be much the better of the two.

Pte. W. R., was wounded in the left loin by a large fragment of shell on July 7, 1917. The foreign body, which was 2½ inches long, was removed from the neighbourhood of the lower pole of the left kidney by Captain Meyer at a casualty clearing station. The lower third of the kidney was found "badly lacerated," and was treated by packing and B.I.P.P. There was no leakage of urine. On July 18, the urine was reported to be normal. When examined at a base hospital, there was a large granulating wound just below the twelfth rib on the left side posteriorly.

On July 23, 1 c.c. of phenolsulphonephthalein was injected into the muscles of the gluteal region. The bladder was emptied by catheter two hours later; 50 per cent of the drug was recovered from this specimen.

On July 24, i.e., seventeen days after injury, the urine was found free from albumin, pus, and blood, and the patient was cystoscoped. The bladder was found to be normal, and with no change in the appearance of either ureteral orifice. One c.c. of phenolsulphonephthalein was injected intravenously, after catheters had been introduced so as to collect the urine from each ureter separately. The patient was under an anæsthetic, and the drug appeared on both sides ten minutes after injection. The catheters were allowed to remain in the ureters for twenty minutes after the appearance of the drug. The following are the results of the examination. On the right side, 4·5 c.c. of urine were collected in thirty minutes from the time of introduction; this quantity contained 22·5 per cent of the total amount of phthalein injected. On the left side, 3·7 c.c. of urine were collected in the same time, containing 18·5 per cent of the total amount of phthalein injected. Allowing for the difference in amount of the fluid collected from the two sides, the percentage of phthalein in the specimens was almost identical. Similarly, the quantity of urea excreted per c.c. was found equal on the two sides. No appreciable leakage of fluid had taken place by the sides of the catheters while in the ureters.

The result of this investigation shows that a kidney with a badly lacerated lower pole had completely recovered its function seventeen days after injury. The only difference between the two sides was a slightly diminished output on the affected side.

I am indebted to Captain Keith, of Johns Hopkins University, for the estimations in these cases.

Urinary Fistula.—Urinary fistula is very likely to occur under the following conditions: (1) When the pelvis of the kidney is wounded; (2) When a laceration of the parenchyma extends so deeply as to involve the pelvis; (3) When the ureter is injured. Wounds of the body of the kidney of a perforating character are not likely to lead to leakage of urine, though

these may have passed through the infundibula or calices. Many cases of the present series may be presumed to have had such perforating wounds, but the number in which a urinary fistula has been present is extremely small, and in these it is probable that the missile had passed obliquely through the pelvis in addition to perforating the kidney. In *Case* 36, this may have happened. In *Case* 33, the foreign body was felt to be in the substance of the kidney, and had probably involved the pelvis as well; this foreign body disappeared later, possibly by way of the colon.

In the present series, 9, or possibly 10, of the 42 cases, had a leakage of urine from the wound in the parietes. Two of these were known to be due to injury to the ureter, as seen at operation, and in several it is stated that the wound in the body of the organ had extended to the pelvis. In the cases in which the kidney was removed and a through-and-through wound found, not involving the pelvis, no leakage was discovered. It is possible that a few drops may have exuded at the time of the injury, and that the infiltrated mass usually seen around the kidney was in part due to the irritation so produced.

The leakage may appear at once, when it may be presumed that the ureter or pelvis has been torn during the transit of the missile, as in *Cases* 1, 3, 4, and 5; or it may be delayed, when it may be presumed that sloughing of a portion of the wall has taken place as a result of the damage inflicted. In *Case* 27, for instance, a retroperitoneal hæmatoma was found at operation, but urine did not appear in the wound until a week had elapsed. The urine may, in a given case, accumulate, and may later reach the surface; but in the case just referred to a drainage tube had been inserted, so that a free passage was left for its escape. A leak immediately after injury is comparable to primary hæmorrhage from a wounded artery, and may be called *primary* leakage, while a leak occurring after an interval of days is comparable to secondary hæmorrhage from a damaged vessel, and may be called *secondary* leakage. In the latter case the missile has probably damaged the pelvis or ureter, a portion of which gives way later, exactly as in the case of an artery under similar circumstances. Leakage of urine may last for a few days only, as in *Cases* 1 and 5, or it may last for months, as in *Case* 4. The ultimate result will of course depend on the size of the opening and the amount of destruction. Complete division will require a plastic operation or nephrectomy.

In *Case* 3, a note accompanied the patient from the clearing station stating that the ureter was found divided below the pelvis of the kidney, and that blood and urine were found in the peritoneal cavity. It is improbable, I think, that *complete* division had taken place, as the leak ceased, though no attempt was made " to close it (the ureter), but a drain was inserted through the loin."

In *Case* 27, already referred to, for a time all the urine from the left kidney came through the lumbar wound, as ascertained by cystoscopy and ureteral catheterization. It was desirable here to determine, if possible, the amount of damage to the ureter. This was accomplished as follows: Collargol was injected by a ureteral catheter through the cystoscope into the lower end of the affected ureter. Radiograms were taken, and the result is seen in *Fig.* 199. It was found that some of the collargol had escaped from

the ureter into the surrounding tissues, but some had passed on to the pelvis of the kidney, distending it and the terminal calices. The deductions which we drew from a study of this radiogram were as follows :—

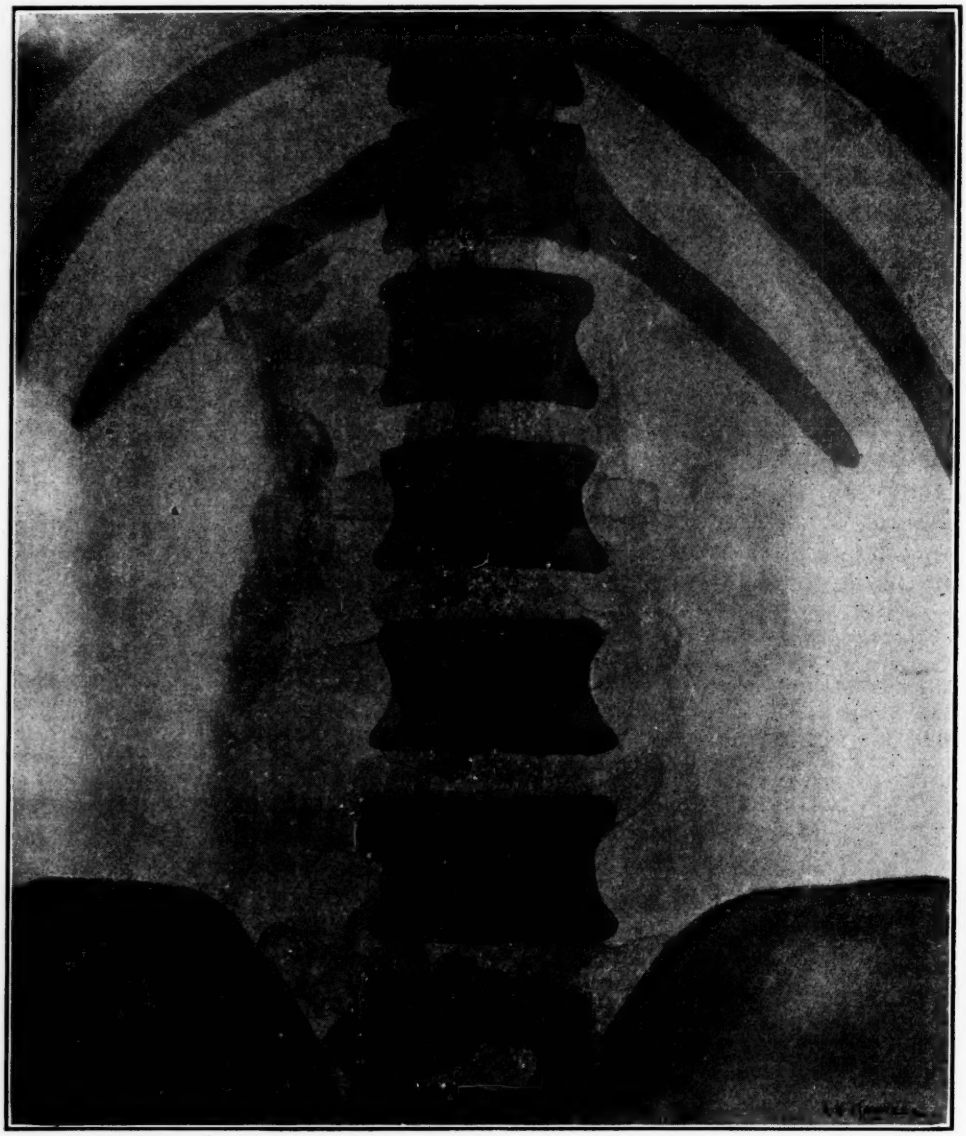

FIG. 199.—*Case* 27. Collargogram of injured ureter. The collargol has escaped from a hole in the ureter, and has extravasated widely along the course of the duct. (Drawn from a radiogram.)

1. The hole in the ureter was of moderate size, and did not prevent the passage of the collargol to the pelvis of the kidney.

2. There was a cavity surrounding the ureter, filled with collargol which

had escaped from the rent in it. This was taken to be a cavity in the position of the former hæmatoma.

3. There was hope that the opening in the ureter would close. This hope was justified, as the urine ceased to flow from the wound six weeks after its first appearance.

We did not venture to locate the exact spot in the ureter at which the hole was situated, but the method just described might be of service in this respect in similar cases in future.

Although no case in the present series required any treatment for the leakage *per se*, it is not to be assumed, of course, that such results are always to be expected. Severe damage to either pelvis or ureter will necessarily involve a permanent fistula, failing successful plastic operation.

The after-histories of the cases which have undergone spontaneous cure will be interesting to follow, and hydronephrosis may safely be predicted in some, from contraction of the scar tissue in the tube itself or in the surrounding parts.

In *Case* 15, the urinary fistula was associated with a fæcal fistula, from damage to the colon. Both fistulæ closed in time, but nephrectomy for secondary hæmorrhage was required later.

Treatment of Urinary Fistula.—Very little is required in the way of treatment in these cases while at the base. If there is evidence of accumulation of urine in a cavity, a way of exit must be provided. Otherwise we have left them severely alone. The flow of urine over the wound surfaces does no harm. If the fistula persists, plastic operation or nephrectomy may be required.

CAUSES OF DEATH.

The chief causes of death in injuries to the kidney, as seen at the base, are sepsis and secondary hæmorrhage. Associated injuries were responsible for most of the deaths in the present series. Thus, 5 cases had spinal injury, 1 had injury to the pancreas and severe sepsis, 1 had multiple wounds and a hæmothorax, and 1 died from intraperitoneal secondary hæmorrhage unconnected with the kidney; 3 died from sepsis and secondary hæmorrhage from the kidney. This makes a total of 11 deaths while the patients were in France. *Case* 4 died in England about six months after receipt of his injury; the immediate cause of his death was pneumonia.

I cannot conclude without tendering my most sincere thanks to those medical officers who have so willingly assisted me in the collection and examination of these cases. I am also deeply indebted to Captain Herbert Henry for his assistance in working out the pathology, and to the Medical Research Committee for the services of their artist, Sergeant Maxwell, R.A.M.C., whose excellent drawings illustrate the text.

SHORT SUMMARY OF CASES.

Case 1.—Pte. S., under the care of Capt. Edye. Bullet wound. Admitted base hospital Sept. 28, 1915. Entry, mid-axillary line, left side, in ninth intercostal space. Exit, on level with first lumbar spine, half an inch from middle line, same side. Blood-stained urine per urethram and some urine from exit wound. Temperature normal and blood absent from urine two days later. Urine ceased to come from wound same time. Evacuated to England, doing well, Oct. 6, 1915.

Track of Bullet.—Probably as follows: pleural cavity, diaphragm, kidney, and pelvis of kidney. Possibly involved a transverse process.

Case 2.—Bugler S., under the care of Capt. Cole. Bullet wounds. Hit on Oct. 16, 1915. Admitted base hospital Oct. 19, suffering from hæmaturia, breathlessness, and præcordial pain. Multiple wounds. Compound fracture of left humerus, and wounds of both arms and both legs. There was an entrance wound, caused by a bullet, between ninth and tenth ribs in nipple line, very small, and partially sealed. Large wound, apparently superficial, in back, about one inch to right of vertebral column, opposite first and second lumbar vertebræ. Abdomen rigid. Patient died a few days after admission.

Post-mortem Report by Capt. Hopwood.—Right side of thorax full of blood-stained fluid, 3 pints. Right lung collapsed. No fluid left side. Recent pericarditis, some blood-stained fluid in pericardium. There was a hole through diaphragm in front, near costal margin. A ragged wound through lower border of right lobe of liver. This went right through the latter, and admitted two fingers. Abdominal cavity full of blood-stained fluid. Left kidney enlarged. Right kidney nearly torn in half, the space between the two halves being filled with dark blood-clot.

Track of Bullet.—Through an aperture in right nipple line, between the ninth and tenth ribs, avoiding right lung, through pleural cavity, diaphragm, right lobe of liver near lower edge, through kidney, and out through muscles of back at level of disc between the first and second lumbar vertebræ, a little to right of middle line. The wound of exit would just admit the little finger.

Case 3.—Pte. R., under care of Capt. Driberg. Bullet wound. Wounded Nov. 16, 1915. Entrance wound in front, left lower quadrant. Operation at a casualty clearing station. Eight perforations in three and a half feet of small intestine. Four feet resected. Left ureter found "divided" below pelvis of kidney. No attempt was made to repair it, but a drain was inserted through left loin. Blood and urine in peritoneal cavity. Abdomen closed. Drained.

Track of Bullet.—Anterior abdominal wall, small intestine, ureter.

Progress good; no urine passed by loin wound after arriving at base, about ten days after injury. Evacuated to England with urine free from pus and blood.

Case 4.—Rfm. McC., under the care of Capt. Driberg. Shell wound. Wounded Nov. 23, 1915. Five wounds in back, right side. Largest resembled a lumbar nephrectomy wound. Shell fragments had been removed at a casualty clearing station. Had much hæmorrhage from large wound after injury. Admitted base hospital, Dec. 2. The large wound exposed the kidney, which protruded when the patient coughed. Urinary fistula. Exposed kidney somewhat excoriated. On Jan. 4, 1916, a pocket of pus at the upper part of wound evacuated. Quantity of urine per urethram varied from 16 ounces to 65 ounces in twenty-four hours. On Jan. 10, very little leakage. Cystoscoped, Jan. 17: Ureteral catheters passed easily into pelves of kidneys. Before catheterization, urine could be seen issuing from right ureteral orifice, which was somewhat rounded in shape and slightly puffy. Urine from bladder: alkaline, sp. gr. 1012, contained ammonium urates, triple phosphates, many organisms, and a few bladder cells. From right ureter: alkaline, sp. gr. 1016, ureteral epithelium, a few pus cells, numerous red cells, numerous organisms, ammonium urates, triple phosphates, and some epithelial casts. From left ureter:

alkaline, sp. gr. 1022, no pus, sterile, blood cells (trauma of catheter). The organisms referred to were *B. proteus* and Gram-positive cocci. The pathological report was furnished by Capt. A. G. Ritchie.

Patient after evacuation to England was under care of Major Davies of 5th Northern General Hospital, who kindly reported progress of case. The urinary fistula had closed before evacuation. Major Davies reports on May 15, 1916: Empyema, subdiaphragmatic abscess, several operations. Free discharge of urine from fistula for weeks, ultimately closed, but patient contracted pneumonia in unaffected lung, and died on May 6, 1916. In a subsequent letter, Major Davies adds, "When he died, his urinary fistula and the chest openings had closed, and he had been out for several days, and seemed to be picking up rapidly when he contracted pneumonia in the sound lung which killed him in four days."

Track of Missile.—Lower part of pleura, diaphragm, pelvis of kidney.

Case 5.—Pte. M., under the care of Capt. Bryan. Rifle bullet. Wounded Feb. 18, 1916. Note from Capt. Dew, from a casualty clearing station, stating that the patient had an injury to the kidney, that there was a slight trace of blood and albumin in the urine, and a urinary fistula, and that the general condition of the patient was good. On admission to base, a small entrance wound was found 2 in. to the right of first lumbar spine and 4½ in. above the level of the anterior superior spine of the ilium. Exit wound over right lower ribs (eleventh). No fistula. Slight rigidity right iliac region. Slight dullness right lower chest. Some pain on coughing. *X* rays show fracture of eleventh and twelfth ribs. Evacuated to England on Feb. 29, doing well. This was evidently a wound of the pelvis of the kidney.

Track of Missile.—Posterior abdominal wall, kidney, peritoneal cavity, liver pleura, chest wall.

Case 6.—Pte. A., under the care of Capt. Driberg. Bullet wound. Wounded March 9, 1916.

Probable Course of Missile.—Through muscles of posterior abdominal wall, external to left renal region, across spinous process of twelfth dorsal vertebra, through outer part of right kidney, through right lobe of liver, diaphragm, and pleura, probably missing lung, then through chest wall and right upper arm.

Hæmaturia was present. There was no pus in the urine, which was alkaline, sp. gr. 1016, and contained red blood cells and triple phosphates. Empyema. No hæmoptysis. Frequency of micturition. Bullet casing and wood from rifle removed from arm. No bile in urine and no jaundice. An abscess formed in liver and was drained. A good deal of necrosis of liver substance.

This was a transverse wound which, from its course, apparently just missed the left kidney but wounded the right one.

Case 7.—Pte. J. B., under the care of Capt. Bryan. Shell wound. Wounded on March 14, 1916. Entrance wound, right side, level with disc between twelfth dorsal and first lumbar vertebræ in posterior axillary line. Also wounds over right pubic spine, right buttock, fold of buttock, and right thigh. Admitted to base hospital March 17. On March 20, laminæ of eleventh and twelfth dorsal and of first and second lumbar vertebræ removed, and shell fragment extracted from left side of theca between the eleventh and twelfth dorsal vertebræ. Two nerves were found divided. Urine contained blood and pus when catheter was used on March 18. The wound involved right eleventh rib and tip of twelfth. On March 21 abdomen full and tender. Paraplegia. Shell did not strike kidney itself. The patient died.

Post-mortem.—Both kidneys enlarged and congested. Ureters dilated but not thickened. On the upper pole of kidney of right side, between capsule and cortex, a hæmatoma. Beneath this an ecchymosed wedge-shaped area, with base uppermost, in the cortex and just involving pyramids.

Case 8.—Pte. M., under the care of Major West. Bullet wound. Date of wound, March 15, 1916. After being hit, a good deal of pain on breathing. Blood in urine.

No vomiting. Right side of abdomen rigid above umbilicus. Entrance wound, just behind mid-axillary line, lower part of chest.

Track of Bullet.—Chest wall, pleural cavity, diaphragm, peritoneal cavity, liver, and kidney.

With opaque ureteral catheter in position, and radiography, bullet located behind kidney or ureter at level of lower pole. On March 28, bullet removed from this situation. The bullet had passed through the kidney from front to back near hilum. Except for the track of the bullet the kidney looked healthy. Cystoscopy: Urine from both sides was normal, sp. gr. 1015. Complete recovery.

Case 9.—Rfm. W., under the care of Major West. Bullet wound. Date of wound, March 17, 1916. Through-and-through wound.

Track of Bullet.—Muscles of right side of back, transverse process of first lumbar vertebra or just above this, kidney, liver, peritoneal cavity, chest wall.

Capt. Taylor, of a casualty clearing station, saw him on March 18, and noted the following: Marked hæmaturia, vomiting (once), pulse 120, and feeble. Patient pale and cold. Abdomen tender and rigid. Laparotomy by Capt. Taylor same day: Blood in abdominal cavity, right lobe of liver perforated, colon bruised on inner side, œdema round duodenum, but no lesion or perforation of abdominal viscera. Under surface of liver still bleeding. Packed with gauze. Wall closed in layers. Four days later, urine clear; omentum protruded, replaced under anæsthetic. March 28, urine blood-stained. March 31, severe hæmaturia, blood-clots, vomiting, anæmia. Same day, nephrectomy. A large mass of infiltrated flesh-coloured perirenal tissue. An opening into peritoneal cavity found, and portion of liver projecting into nephrectomy wound. The opening was large. Bullet went through kidney close to hilum. Patches of yellowish-white colour at bases of pyramids opposite wound in kidney. Apices of all pyramids pale, and patches of yellowish white in renal columns between the affected pyramids. From small entrance wound, a streak of white extended outwards. Exit wound, a round irregular opening with a margin of whitish yellow round part of circumference. April 13, large clots washed out of bladder. Well-marked general cystitis. Urine, after operation, averaged 50 to 60 ounces per diem. Recovery.

Case 10.—Pte. C., under the care of Major West. Bullet wound. Wounded March 18, 1916. Admitted base hospital, March 20. Complete paraplegia below level of iliac crests. Hæmaturia. Died April 2.

Short Report of Post-mortem.—Entrance wound, right side. No exit. Small left hæmothorax. Some collapse left lung. Right kidney wounded at upper pole, and spinal cord divided at level of twelfth dorsal vertebra.

The notes of this patient are incomplete.

Case 11.—L.-Cpl. B., under the care of Capt. De la Cour. Bullet wound. Wounded March 21, 1916. Range 300 yards. Stooping at time. Passed water twenty-seven hours after being wounded, and noticed that it was bright red. Wound of entry small, aseptic, 12 cm. to right of middle line of back and ½ cm. above crest of ilium. Bullet, pointing down, localized as lying 16 cm. from back, about 9½ cm. from mid-line in front, same side, and 10 cm. below level of second costal cartilage. Admitted to base hospital on March 23. Hæmaturia. Abdomen rather full and tympanitic. Very acute tenderness over liver. Some rigidity, right side. No vomiting. Temperature 101·2°, pulse 94, respirations 30. Has had old bronchitis. Bullet appears to have injured posterior border of right kidney, and the liver. Urine remained slightly stained until April 9, i.e., about nineteen days. Quantity of urine averaged 40 to 50 ounces in twenty-four hours. Bullet was judged to be in vicinity of diaphragm. Cystoscopy, three weeks after injury: Right ureteral orifice, a little puffy, with slight congestion around. Anuria on right (affected) side for several minutes after passage of ureteral catheter. Flow from left side free from moment of introduction of catheter. Indigo-carmine came through on both sides fifteen minutes after injection into buttock. Colour deeper on uninjured side. Specimen from right side: sp. gr. 1005,

acid, clear, trace of albumin, renal cells and epithelial casts, ureteral epithelium, no pus, no blood. Specimen from left side : sp. gr. 1010, acid, clear, trace of albumin, hyaline and epithelial casts, renal cells, ureteral epithelium, oxalate of calcium crystals. The patient was discharged to England in good condition.

Case 12.—Sergt. H., under the care of Major West. Bullet wound. Wounded while standing, on March 20, 1916. Range about 300 yards. Seen by Capt. Meyer at a casualty clearing station, who sent notes as follows to base : " Pulse 128, temperature 97°, no abdominal rigidity, vomited twice, very marked hæmaturia, which ceased in two days. Lost a good deal of blood by external wound." Admitted base hospital, March 24.

Track of Bullet.—Abdominal muscles, peritoneal cavity, omentum, descending colon(?), left kidney, and posterior abdominal wall. Through-and-through wound.

Had cystitis, although no catheter had been passed. Cystoscopy, April 11 : General cystitis. Indigo-carmine injected into buttock appeared on both sides in about fifteen minutes, under ether. Specimens from right side : sp. gr. 1005, trace of albumin, no blood, a few pus cell (?), cells from ureter, no micro-organisms. Left (injured) side : sp. gr. 1005, trace of albumin, blood cells, no pus cells, cells from pelvis of kidney and from tubules, *Streptococcus pyogenes* and *B. coli*. Recovery.

Case 13.—Pte. J. W., under the care of Major West. Bullet wound. Wounded in erect position at a range of about 500 yards on April 18, 1916. Entrance wound, right side, level of tenth dorsal spine, posterior axillary line. Bullet located by *x* rays, lying 2·4 cm. from middle line opposite fourth lumbar vertebra and 1 cm. from the plate on right side. Note from Capt. Stevenson of a casualty clearing station : " On admission, vomiting, hard rigid abdomen. Decided to wait before operating. Marked hæmaturia, which is improving. Still has attacks of pain in right side, probably due to blood-clots in ureter. Hæmaturia for about a week. Hæmothorax, right side. Some cough. No hæmoptysis." Admitted base hospital, April 22. No abdominal symptoms. Urine contains blood and pus. April 27, no visible blood. April 30, laboratory reports blood and pus. May 12, a few red blood cells and much pus, also very numerous streptococci and a large Gram-positive bacillus. Quantity of urine, 50 to 60 ounces in twenty-four hours.

Track of Bullet.—Right side, chest wall, pleura, lung, diaphragm, peritoneal cavity, liver, kidney, and erector spinæ.

Had slight fever for about a week. Cystoscoped, May 16 : Slight degree of cystitis. Indigo-carmine came through twelve minutes after injection. Colour deeper on left or uninjured side. Flow apparently more on left side, but some escaped by the side of the catheter on the right. Specimen from right side : acid, sp. gr. 1015, *Streptococcus pyogenes*, pus, renal cells from tubules, no casts. From left side : acid, sp. gr. 1025, sterile, pus cells (?), hyaline casts, accidental blood. Patient made a good recovery.

Case 14.—Pte. W. C., under the care of Capt. Kelly. Bomb wound. Accidentally wounded, Feb. 22, 1916. When admitted to a casualty clearing station was in a collapsed condition. Had retention of urine. Specimen removed by catheter contained blood. This diminished, and was slight in amount on Feb. 24. Admitted base hospital Feb. 25. In addition to slight wounds of extremities, there was a small entrance wound on left side of back, 4·2 cm. above highest point of iliac crest and 9 cm. from mid-line, opposite interval between second and third lumbar spines. Foreign body retained. Hæmaturia ceased a few days after admission. He had slight fever, but this subsided in a few days. *X* rays showed a small foreign body 4·4 cm. from skin of back and 3·25 cm. from middle line just below lower border of last rib on left side. There were two smaller fragments, evidently quite superficial. An opaque ureteral catheter was introduced on March 9, and stereoscopic radiograms were taken. The two small pieces of shell were well behind the opaque catheter. The larger one was in the same plane as the ureteral catheter and on a level with its upper end, but much nearer the mid-line. The foreign body was located as lying near the inner margin of the upper pole of the kidney. On introducing the cystoscope,

before ureteral catheterization, a clot of blood was seen at the mouth of the left ureter. Specimens from right side: acid, sp. gr. 1020, urates, albumin, a few blood cells (trauma of catheter), no casts, no pus cells, *Staphylococcus pyogenes aureus*. Left side: acid, sp. gr. 1005, slightly cloudy, stained with blood, loaded with albumin, pus cells in quantity, cells from pelvis and ureter, much cellular detritus, *Staphylococcus pyogenes aureus* and *Streptococcus pyogenes*.

The patient died, unexpectedly, on March 17. The post-mortem was made by the late Capt. Tanner. The abdominal cavity was full of blood. The perirenal tissues were much infiltrated and thickened. On the posterior surface of the kidney was an oblique track extending from the posterior border upwards and inwards, grooving the surface, as far as the upper pole. The missile was found between the kidney and the suprarenal capsule (see *Fig.* 195). The perirenal thickening involved the tail of the pancreas, and it was from this region that the hæmorrhage took place. The spleen was quite normal. The appearance of the kidney, and the results of the microscopical examination of sections from different parts and from the opposite kidney have already been described (see section on EFFECTS OF MISSILE ON KIDNEY).

Case 15.—Pte. T., under the care of Capt. Morgan. Shell wound. Wounded May 28, 1916. Capt. Meyer saw this case at a casualty clearing station. The wound was on the right side, and involved the ascending colon. Operation, May 29: A large hæmatoma on the outer side of colon. Much blood-clot removed from here. Laparotomy in middle line by Capt. Meyer, who found a hole in the colon and sutured it. Drainage anteriorly and posteriorly. May 31, fæces and urine began to escape from posterior wound. On June 8, a secondary hæmorrhage. Blood flowed from loin and into bladder. Patient was pulseless. June 9, pulse improved, rate 130. June 13, another hæmorrhage from loin and into bladder. Patient now absolutely pulseless. June 14, pulse again improved. June 16, fæcal fistula was closed. No hæmaturia now. Loin wound was opened and pus evacuated. Improved since. Evacuated to base. On June 27, another secondary hæmorrhage, filling up bladder. Severe suprapubic pain. A further hæmorrhage on June 28. On June 29, wound in loin extended and kidney explored. Laceration in lower pole, extending into pelvis. Some extravasation of blood in perirenal tissues. Sharp triangular piece of metal removed from just behind kidney. Kidney was removed.

Track of Wound.—From before back, towards loin, involving colon and kidney in transit.

Blood evacuated from bladder by catheter. Organisms in great numbers were subsequently found in urine, coliform, streptococcal, and diphtheroid. July 1, some cystitis. No blood. Improving. Patient made a good recovery.

Case 16.—Driver B. P., under the care of Capt. Thomas, at a casualty clearing station. Bullet wound. Injured June 5, 1916. Entrance wound right side at costal margin, 9·2 cm. from middle line in front. Exit wound, 7 cm. from middle line behind and 8½ cm. above highest point of iliac crest. Catheter required same night. Hæmaturia for six days. Catheter required for two days. No evidence of intestinal injury and no external bleeding. Temperature reached 100° at night for a few nights.

Track of Bullet.—Anterior abdominal wall, peritoneal cavity, liver, kidney, perirenal fat, and muscles of back.

On June 18 a small amount of blood again appeared in urine (twelve days after injury). June 19, no blood. June 26, a few pus cells in urine. Evacuated to England June 28, doing well. Only a few days at base.

Case 17.—Pte. S., under the care of Capt. Tobias. Shell wound. Hit June 11, 1916. Three wounds of back and some small wounds of upper arm. Admitted on June 12 to a casualty clearing station under Capt. Mann. Patient was pale, shocked, temperature 97°, pulse 108, respiration 40. Crepitus and dullness at base of left lung, dyspnœa, hæmoptysis, vomiting, hæmaturia, tenderness left hypochondrium.

June 14, urine clear. Admitted base hospital June 20. Urine then contained blood and pus. Temperature for a few days reached 102° in the evening, but gradually settled. Fracture of ninth rib on left side. Entrance wound on right side, size of a sixpenny piece, 12½ cm. above iliac crest, and 8½ cm. from mid-line. On left side, two superficial wounds. *X* rays show foreign body about 7 cm. to right of body of second lumbar vertebra and 4½ cm. from plate on back. No foreign body on left side where there are wounds. Cystoscoped, June 23: Ureters catheterized. Indigo-carmine injected into buttock. Both ureteral specimens show colour in ten minutes. The left (uninjured) side soon became more deeply stained. Both sides, sp. gr. 1015. There were a few red cells on the right (injured) side, but pus and micro-organisms were absent on both sides. On June 24, the piece of shell was removed from loin. It lay posterior to right kidney, the lower pole of which it had grooved to the depth of a quarter of an inch. There was much matting of perirenal fat. The injury to the lung on the left side was unconnected with the missile which injured the kidney on the right side.

Case 18.—Pte. B., under the care of Capt. Tobias. Shrapnel ball. Wounded, June 11, 1916. Multiple wounds. There was an entrance wound in left loin just above crest of ilium posteriorly. No exit. Retention of urine. Paraplegia. Complained of abdominal pain, which was relieved by catheterization. Hæmaturia. June 16, persistent vomiting. High swinging temperature. Vomiting continued, with abdominal pain, not localized. No tenderness or rigidity. Very slight dullness in right flank. June 20, vomiting and delirium until death.

Post-mortem.—Ball had passed obliquely upwards from the entrance wound, traversing third, second, and first lumbar vertebræ, passing through spinal canal, and wounding right kidney at upper pole. It had then passed into peritoneal cavity, and was found free in right iliac fossa. No other abdominal lesion. Recent secondary hæmorrhage from kidney. Subphrenic abscess. Cauda equina contused. No hole in theca.

Case 19.—Cpl. F., under the care of Capt. Ridewood. Rifle grenade. Wounded June 13, 1916, in back, thigh, and left hand. The wound in the back was on the right side. Hæmaturia for first time June 14. Urine clear to naked eye June 15. *X* rays showed shell fragments in right loin. There was a punctured wound 5·8 cm. above highest point of iliac crest and 10·4 cm. to right of centre of spine. Two fragments seen in skiagram. The smaller piece was 10·6 cm. deep from surface of back opposite lower part of body of first lumbar vertebra. The larger part was 9·7 cm. from surface of back opposite disc between first and second lumbar vertebræ. Both fragments were 5 cm. distant from right border of vertebræ. Cystoscopy, June 20: Bladder and ureteral orifices normal. Opaque catheter introduced into pelvis of kidney on right side. Radiography shows upper fragment 3·8 cm. anterior to catheter and lower fragment 2·2 cm. anterior to catheter. Both fragments are therefore probably anterior to kidney. The upper fragment ought to be in the liver, and the lower one in or touching the liver.

Track of Missiles.—Both probably took the following course: Erector spinæ quadratus lumborum, kidney, and peritoneal reflection between it and the liver.

Specimens of urine were taken from each ureter. Right side: sp. gr. 1015, blood-stained, no pus, epithelial cells from ureter. Left side: sp. gr. 1020, deep amber, no pus, a few red cells. Bacteria not seen in either specimen. Evacuated to England on June 22. The patient was recently heard of through the Medical Research Committee, and remains free from urinary symptoms.

Case 20.—Pte. A., under the care of Major West. Bullet. Hit in right loin. Laparotomy by Capt. Gross at a casualty clearing station. Large perirenal hæmatoma, and apparently perforation of right kidney by bullet. Wound closed, no abdominal viscera involved. The bullet had been previously removed by regimental surgeon. No history of hæmaturia. On June 20, 1916, a small abscess formed in the wound, and this was opened by Major West at a base hospital. June 26,

Capt. Henry found pus in small quantity, but no blood in urine. June 28, the wound again required opening up. Subsequent progress good. Notes of this case are incomplete.

Case 21.—Gnr. J. W., under the care of Capt. Whittington. Grenade wound of back. Wounded July 6, 1916. Passed urine containing blood two hours after injury. The cause of injury was a small fragment of metal, which was retained. There was rigidity and tenderness of right side of abdomen. No vomiting. Bowels opened with enemata. Urine contained blood until July 12, when it was found normal.

Case 22.—Pte. S., under the care of Capt. Bazett. Shell. Wounded July 16, 1916, in lateral aspect of right loin. Also a wound of right forearm. No history of hæmaturia. Missile retained in lumbar region. The day after admission to a base hospital, became suddenly blanched, and complained of great pain in right lumbar region, with rigidity. Pulse became very rapid. Operation, July 18: Transverse abdominal incision at level of umbilicus. Some blood-stained fluid in peritoneal cavity. Colon much ecchymosed. A large retroperitoneal hæmorrhage. Kidney explored. Found wounded, and removed. Clot cleared out. The kidney showed an entrance wound anteriorly in the lower third, and a larger wound on the posterior surface. There was much ecchymosis of the kidney. A patch of necrosis extended from entrance wound towards ureter. Patient died the same day.

Case 23.—Pte. A., under the care of Capt. Tobias. Shell. Wounded on July 14, 1916, in right side of back at level of crest of ilium, 2 inches from mid-line. Missile retained. *X* rays show missile opposite second lumbar vertebra about 3 inches from mid-line, and $3\frac{1}{4}$ inches from plate on back. Urine contains red blood cells, pus cells, and granular casts. No previous kidney trouble. On July 18, had two rigors, temperature rising to 101° in one and 104·8° in the other. The fragment was located just below the last rib near its outer part. There was an irregular shadow of doubtful nature in the neighbourhood of the ureter, opposite the third lumbar vertebra on same side. Operation, July 19: Exploration of kidney. Normal kidney found. Missile had passed through crest of ilium, across line of ureter, leaving on its way a wad of clothing. This may have been the source of the irregular shadow. The track passed on in front of the lower pole of the kidney through an aperture in the peritoneum, and was not further followed. It was thought that the condition of the urine might have been due to contusion of the ureter or kidney. There was some ecchymosis in the track, but the kidney was not obviously affected.

Case 24.—Pte. W. E. E., under the care of Major McEwen. Shell. Wounded in back, left side, July 21, 1916. Fragment entered between eleventh and twelfth ribs in posterior axillary line, and probably involved the lower part of diaphragm. An hour after being hit he noticed blood in his urine. Admitted to base hospital on July 23. July 24, urine still coloured, but no pus in it. Gas infection in and around wound. July 26, Major McEwen removed a piece of shell with clothing from the depths of the wound, slightly anterior to the lower pole of kidney. There was a good deal of oozing after the operation. Urine escaped from wound in loin. July 27, severe secondary hæmorrhage into bladder. Wound rapidly opened up and pedicle clamped. Later in the day, nephrectomy. Death, nine hours later. Kidney was enlarged. A large ragged wound was found extending into the pelvis. Area around the wound ecchymosed. Cortex pale and stippled with dark dots. Pyramids pale-red in colour. The kidney shows disorganization around the ragged wound, and an area of necrosis near cortex. For microscopical examination see under EFFECTS OF MISSILE ON KIDNEY.

Case 25.—Lieut. S., under the care of Major Martin. Bullet. Wounded July 23, 1916, through right loin. Same day passed blood in urine. Entrance wound, mid-lateral line, 4 inches above iliac crest in tenth intercostal space on right side. Exit wound, on same level half an inch to left of spinous process of second lumbar vertebra.

Probable Course of Bullet.—Chest wall, lower part of pleural cavity, peritoneal cavity, liver, lower half of right kidney, across back to emerge on left side, possibly damaging bone of lumbar spinal canal in its passage across the middle line. No spinal symptoms.

Admitted Guy's Hospital, London, on July 29. There was a note from this hospital to say that "the entrance wound was healed, but the exit wound was septic." On evacuation to England he still had blood in his urine. On Aug. 6, about a fortnight after his injury, hæmaturia was noticed. Aug. 21, very profuse hæmaturia; about a pint and a half of pure blood was passed. After each attack the urine gradually became free from blood. At no time were pus cells found. Aug. 26, very profuse hæmaturia. This continued until his kidney was removed on Aug. 29. Recovery uneventful.

I am indebted to Mr. C. H. Fagge, of Guy's Hospital, for the following note: "Lieut. S. had several hæmorrhages, and I operated for progressive anæmia, rising pulse, and pain so severe that he said that he could not stand it any longer. The kidney is in Guy's Hospital Museum. The depressed area (just below the middle of the organ and at its outer border) was quite yellow, and looked like an infarct; there was a tear above the yellow area, and some blood and pus around the kidney, but it was evidently a mild infection. There was no wound of the pelvis."

Case 26.—Pte. H., under the care of Lieut.-Col. Upjohn. Shell wound over left erector spinæ opposite second lumbar vertebra. A large incision had been made in erector spinæ at a casualty clearing station. Admitted to base hospital, Sept. 22, 1916. *X* rays showed a large piece of shell, deeply situated, probably involving the upper half of left kidney. Microscopical examination of the urine showed red and white blood cells. There was much albumin present. The temperature ranged from 100° to 103°, and the pulse was rapid. On Oct. 11 nephrectomy was decided on. There was free venous bleeding, and Col. Upjohn found it impossible to deliver a large soft friable kidney through the loin with safety. There were firm adhesions of the capsule to the perinephric tissues, and in trying to remove the kidney after decapsulation, it was found divided into an upper free third and a lower, less free, two-thirds. The foreign body was found and removed, and the kidney left in position. The patient died on Oct. 13.

Post-mortem.—A small amount of turbid fluid was found in the left kidney peritoneal pouch, but no definite peritonitis. Both kidneys were about twice the normal size, soft, dark in colour, with lighter greyish streaks on section. No areas of distinct suppuration found. The capsule of the right kidney peeled in a normal fashion. The left perinephric tissues were infiltrated with blood, and were thickened and sodden with inflammation. The left detached renal capsule was similarly greatly thickened. The pancreas had been cut across by the shell fragment, and the splenic vein was torn, but the splenic artery was intact. The distal end of the pancreas was black, but still firm. [There is no note of fat necrosis.—A. F.] The kidney was seen to be completely separated into two parts, an upper third supplied by an aberrant artery, and a lower two-thirds receiving the main vessels. The torn surface was greyish, but sections of the kidney substance showed it to be of a dark maroon colour, with the greyish streaks before referred to.

I am indebted to Lieut.-Col. Upjohn for the notes of this case.

Case 27.—Pte. G. S., under the care of Capt. Kelly. Shell. Wounded Oct. 10, 1916. Entrance wound one inch to left of eleventh dorsal spine. No exit wound. No paraplegia. Chest: nil. Abdomen: tenderness in left hypochondrium and left lumbar region. *X* rays showed no foreign body. No blood in urine. Oct. 13, abdomen very distended; vomiting; tenderness and rigidity in left lumbar region. Operation at a casualty clearing station: entrance wound excised. Track could not be followed by finger. Abdomen opened through outer edge of left rectus. No free fluid. No injury to intestine. Large retroperitoneal hæmatoma. Abdomen closed. Hæmatoma drained extraperitoneally through an incision in loin. Oct. 17, urinary fistula (a week after injury). Urine flowed from this, but no blood. Oct. 27, two moderate hæmorrhages from lumbar wound. Admitted to base hospital, Oct. 30.

Patient anæmic and wasted. Moderate fever. Pulse raised. Much urine coming from a deep wound in loin. *X* rays failed to discover any foreign body. (This may have been removed at casualty clearing station.) Tubular breathing and a little dullness at base of left lung. Cystoscopy, Nov. 2 : Both ureteral orifices normal, both exhibit systole and diastole. No fluid from left ; clear urine from right. Catheter on left arrested 6 inches from mouth of ureter. Collargol solution injected (see *Fig.* 199). Skiagram now taken. Fluid had evidently escaped into surrounding tissues from a hole in ureter. Some, however, had reached the pelvis, and distended it and the calices. The urine from the bladder and the right ureter contained some epithelial cells, a few pus cells, and a trace of albumin. Patient was evacuated to England on Dec. 3, with his wound dry. No urine had passed by the wound for three days. The missile here had probably passed down obliquely, injuring the lower part of the pleural cavity, the retroperitoneal tissues behind the kidney, and the ureter.

Case 28.—Pte. W., under the care of Capt. Tobias. Shell. Wounded Oct. 16, 1916. Entrance, tenth chondro-costal joint, right side ; exit, behind, at a slightly lower level, 2½ inches to right of mid-line. No pain in abdomen, but burning pain in back of thigh. Blood in urine. No abdominal tenderness or rigidity. Operation at casualty clearing station by Major Gardner : abdomen opened. Colon uninjured. Foreign body had passed through chest wall, driving a portion of rib into liver. The damaged portion of rib was removed. It was found that there was a groove in outer border of right kidney. The laceration of the liver bled moderately. There was vomiting, with rapid pulse, during the night of Oct. 18, and bile and blood issued from the posterior wound. Patient improved, and was sent to base. Arrived at base hospital on Oct. 29, doing well. Capt. Henry reported much blood and pus in urine. Evacuated to England Nov. 4.

Case 29.—Pte. A. C., under the care of Capt. Kelly. Shell. Wounded Oct. 25, 1916. Entrance wound, left side, just below last rib. No note of blood in urine, Laparotomy by Capt. Rollinson Oct. 28. A little blood in peritoneal cavity. Retroperitoneal hæmatoma. Lower pole of left kidney lacerated. This was packed and drained. Missile not found. Admitted to base hospital, Nov. 6. Wounds clean. Abdominal wound had healed per primam. No blood in urine. Foreign body removed from a swelling over crest of ilium. Urine was examined by Capt. Henry on Nov. 10. It contained a trace of albumin, a few pus cells, and red blood-corpuscles. Evacuated to England, Nov. 15, much improved.

Case 30.—Pte. G. W., under the care of Major West. Shell. Wounded Nov. 13, 1916. Wounds of right foot, and right side of chest. Fractured tibia. A small hæmothorax. Nov. 19, amputation of leg. Nov. 23, some oozing from stump. Nov. 25, passed almost pure blood per urethram. This was the first indication that any injury had been done to urinary organs. *X* rays showed a fragment of shell 2 inches from central line on right side, just external to tip of transverse process of third lumbar vertebra. It was located as being, probably, in the psoas muscle. The entrance wound was in the chest wall, fifth interspace on right side, two finger-breadths outside nipple line.

Probable Course of Missile.—Chest wall, lung, pleura, diaphragm, liver, lower pole of kidney.

The secondary hæmorrhage occurred twelve days after injury. Cystoscopy, Nov. 25. Left ureteral orifice normal and discharging clear urine ; right shows a long rope of blood-clot attached to orifice ; bladder normal. Urine from left side normal ; the few drops obtained from the injured side contained blood but no pus. Operation, same day : kidney removed. The organ was pale in colour (see *Figs.* 191, 192). There was an entrance wound at lower pole about an inch long, surrounded by an irregular ridge. There was a small exit wound on posterior surface. The wound on anterior surface was surrounded in the fresh specimen by a yellowish-white slightly raised area, and there was a similar wedge-shaped area occupying the anterior surface, posterior border, and posterior surface at lower pole. This is well depicted in the drawing by Sergt. Maxwell. The shell fragment was removed from

the spot indicated in the radiogram. The large clots of blood which had accumulated in the bladder were washed out with an evacuator. Cystitis developed after operation. Recovery.

Case 31.—Sergt. D., under the care of Capt. Morgan. Shell. Wounded Nov. 11, 1916. Entrance wound at level of lower border of second lumbar vertebra and 2 inches from mid-line on left side behind. Paraplegia. Admitted base hospital Nov. 19. Nov. 20, abdominal distention was noticed, and very profuse hæmaturia, with vomiting. *X* rays showed a large piece of metal at level of twelfth dorsal vertebra on right side, 3 inches from mid-line and 4¾ inches deep from back. Two days after admission, had rigors, temperature running up to 106°. Nov. 25, blood was still present in the urine. Nov. 26, blood had entirely disappeared, even on microscopical examination.

Track of Missile.—Reconstructed as follows: Skin, transverse process of second lumbar vertebra, cauda equina, body of first and disc between first and second lumbar vertebræ, psoas muscle, right kidney, liver (in which progress of foreign body was arrested). The patient died on Nov. 26.

Post-mortem.—The missile was found to have traversed the body of the second lumbar vertebra, then a vessel passing to the lower pole of the kidney, finally coming to rest in the liver. Hepatic abscess. The right lung was adherent to the diaphragm, and the latter to the kidney. The coloured drawing by Sergt. Maxwell (see *Fig.* 194) is a faithful representation of the appearances seen. The necrosis of the area supplied by the wounded vessel is well depicted, and some of the infiltrated perirenal tissue is shown.

Case 32.—Pte. G., under the care of Capt. Edwards, to whom I am indebted for short notes of this case. Shell. The patient was wounded on Nov. 25, 1916, by a piece of shell which was retained. Hæmaturia was present. On Dec. 24 severe secondary hæmorrhage took place via the external wound. The patient was blanched. Affected kidney removed on Dec. 25, and blood transfusion performed immediately after. The improvement in patient's condition was dramatic and he made a satisfactory recovery. There was a small perforating wound of the kidney near the centre, with an area of necrosis around the points of entrance and exit. For microscopical examination of removed kidney, see section on EFFECTS OF MISSILE ON THE KIDNEY.

Case 33.—Gnr. J., under the care of Capt. Hemmans. Shell. Wounded Dec. 28, 1916. Laparotomy at casualty clearing station, No injury to gut. Spleen intact. Large retroperitoneal hæmatoma. There was a wound in loin. This was opened up, and foreign body was felt in substance of the kidney, but could not be removed with safety. There was a tear in substance of kidney, which was plugged. Lieut. Donaldson, at clearing station, with stereoscopic radiography, located a foreign body lying 8 cm. below skin-mark. The foreign body moved with respiration. When admitted to base hospital, the urine contained a little blood, and urine was leaking from a wound in the loin. The patient was very anæmic, and had been running a temperature up to 104° and a pulse of 120 or so. There had been a good deal of sepsis in the loin, and several incisions for cellulitis had been made. Capt. Gamlen *x*-rayed the patient, but failed to find any foreign body. This may have escaped unnoticed, or may have made its way into a hollow viscus. On Jan. 21, 1917, there was no blood but some pus in urine. Jan. 31, his wounds were almost healed, and there was no leak of urine. He was evacuated to England on Feb. 1. His urine was then free from blood, pus, and albumin.

Case 34.—Pte. W. M., under the care of Capt. Morgan. Shell. Wounded March 4, 1917. Multiple wounds. The wound in right lumbar region was 12 cm. from mid-line behind and 7 cm. above iliac crest, about the eleventh intercostal space. About an hour after being hit, he passed urine stained with blood. When seen at a base hospital, on March 7, abdomen was somewhat rigid, he was vomiting, his urine was dark in colour, tongue brown, pulse 108, temperature 101°. The urine contained

much blood, a very few pus cells, and a heavy deposit of urates. Icteric tinge in conjunctivæ. Slight cough. *X* rays showed a fragment of metal, 7·6 cm. deep from back, 10·6 cm. from mid-line, at level of lower border of twelfth dorsal vertebra. There was also another small piece of metal, probably in muscles of back.

Track of Missile.—Reconstruction shows that it probably grooved the outer border of right kidney and came to rest in the liver.

On March 27, urine only contained a few red cells, a few pus cells, and no bile. Cystoscopic examination discovered very little difference between the specimens drawn from each kidney. Indigo-carmine was delayed on the affected side, taking twenty-five minutes as against twenty on the undamaged side, under an anæsthetic. The specific gravity was equal on the two sides.

Case 35.—Pte. J. S., under the care of Capt. Palmer. Shell. Wounded, March 12, 1917. Small punctured wound 1½ inches above left iliac crest and 1½ inches to left of mid-line. Abdomen was found rigid when admitted to casualty clearing station same day. On March 15, when admitted to base hospital, no abdominal symptoms. Straw-coloured fluid (urine ?) was discharged in small quantity from wound in the loin. *X* rays showed three foreign bodies in the loin. The largest was located just above and in front of the transverse process of the second lumbar vertebra. The other two fragments were minute. Urine examined on several occasions. On March 17, it was reported free from albumin and blood. March 20, a trace of albumin and blood, pus corpuscles in fair quantity, and one or two broken-down granular casts were found. March 23, urine normal. March 27, albumin and blood present. A couple of rises of temperature to 101°–102°. Cystoscopy, March 29. Bladder and ureteral orifices normal. Indigo-carmine came through ten minutes after injection, but was slightly more marked in urine on affected side. Sp. gr. of both specimens, 1020. A few red cells and a trace of albumin on each side. Opaque ureteral catheter was introduced to locate position of foreign bodies relative to kidney. The largest was 4 cm. behind the catheter, and one of the smaller ones was 1·9 behind the catheter. It is probable that the kidney was contused, but not otherwise injured.

Case 36.—Pte. S. B., under the care of Lieut.-Col. Gordon Shaw, to whom I am indebted for the notes of the earlier progress of the case. Revolver bullet. Admitted to casualty clearing station March 11, 1917, four hours after being wounded. Small punctured entrance wound in back at level of third lumbar vertebra, 2 in. to right of mid-line. No exit. Tenderness and rigidity on right side of abdomen. Right flank dull on percussion. Right side of chest dull to level of eighth rib in line of angle of scapula. Patient passed some deeply blood-stained urine. No vomiting. Pulse 104, temperature 101°, respirations 44. Breathing not distressed. Laparotomy, same day: free blood and blood-clot in peritoneal cavity. A punctured wound was found on the anterior surface of the kidney, just to right of second part of duodenum. An entrance wound in liver immediately in front of transverse fissure, and an exit wound was felt in the dome of the liver. Some extravasation of blood behind second part of duodenum. Col. Shaw divided the peritoneum on the outer side of the duodenum, mobilized the latter, and drew it over to left. Wound about 1¼ in. in length discovered on posterior and outer surface of duodenum, extending down to, but not through, the mucous membrane. This was repaired, the duodenum was restored to its position, and the peritoneum sutured. Drainage tube through right flank by stab puncture. Abdomen closed. Next day, double lobar pneumonia. March 13, leakage of urine from loin. March 25, right pleural cavity explored with needle, and sterile blood-stained fluid drawn off. On April 2, urinary fistula practically closed. After his arrival at the base, an empyema on right side was drained by Lieut.-Col. Taylor. On May 27, urine was free from albumin, pus, and blood. Cystoscoped, June 4, about three months after injury: both kidneys secreting well. Sp. gr. on both sides, 1010. Indigo-carmine came through in fourteen minutes on both sides.

Case 37.—Driver R. T. W., under the care of Major West. Shell. Wounded April 3, 1917, in back. Paraplegia. Blood in urine on first catheterization at casualty

clearing station. Entrance wound, half an inch in diameter, 11 cm. to left of spine and just below last rib. Admitted to base hospital, April 6. *X* rays show a large fragment of shell between second and third lumbar vertebræ. Operation, April 8. Laminectomy. Fragment easily found behind cauda equina, which was exposed. Wound was investigated, and found to travel upwards and inwards, with a pocket towards renal region, but no connection with kidney was seen. The latter was therefore probably contused by transference of impetus of missile during passage. Evacuated to England.

Case 38.—L.-Cpl. J., under the care of Capt. Hannigan. Shell. Wounded in left loin, April 9, 1917. Urine removed by catheter, thirty-three hours after injury, contained blood. No vomiting. General condition good. Entrance wound about 1 cm. above iliac crest, left side, and 5 cm. behind line of anterior superior iliac spine. No exit. Admitted base hospital April 11. Still requires catheter. Pulse 92; temperature 100°–102°. Lower quadrant of left side of abdomen dull, tender, and rigid. *X* rays: nil. Slight fever. April 14, pulse and temperature now normal, dullness in flank disappearing; still requires catheter. April 15, urine almost clear. Patient was evacuated to England a few days later, still requiring catheter.

Case 39.—L.Cpl. K., under the care of Major McEwen. Shrapnel ball. Hit April 9, 1917. Multiple wounds. Two in back. One entrance wound in left lumbar region just below ribs and about two inches from spine. Exit over lower ribs, two finger-breadths from costal margin in nipple line. Passed blood in urine day after injury. Some abdominal pain in hypogastric region. Few signs, if any, in renal region.

Reconstructed Track of Missile.—Left kidney, abdominal cavity in region of jejunum and stomach, just outside left edge of liver.

April 26, still passing blood. April 28, blood had disappeared, but a little pus and some albumin were found. A shrapnel ball (one of several that had injured him) was removed from scrotum. Cystoscoped, April 30: ureteric orifice on affected side (left) slightly puffy. Indigo-carmine came through on both sides in eighteen minutes under ether anæsthesia. The colour was, however, deeper on affected side. Specimen from right side: acid, sp. gr. 1010, trace of albumin, no pus, a few epithelial cells, a few streptococci. Left (affected) side: acid, sp. gr. 1005, cloudy, albumin, pus, streptococci a small bacillus like *B. influenzæ*, and a coli-like bacillus.

There was apparently a slightly diminished flow on affected side. Note that the specific gravity was lower on affected side, but the colour of indigo-carmine was deeper.

Case 40.—Pte. P., under the care of Capt. Swan. Shell. Wounded, April 7, 1917, on left side. An hour later, passed urine mixed with blood. Vomited once, On admission to base hospital, entrance wound between eleventh and twelfth ribs, 8 cm. from mid-line, left side. No exit. *X* rays show large piece of metal lying deep to twelfth rib, 6·3 cm. from back and 7·4 cm. from left side of body of first lumbar vertebra. The fragment was 1½ cm. in length. Twelfth rib fractured about middle. Patient has had pain for four or five days in left hypochondrium. On April 17, urine was quite clear. Foreign body judged to be in left kidney. An opaque catheter would have been valuable here, but stress of work in the hospital did not permit. Probably the lower part of pleural cavity and the diaphragm were involved. Very little rigidity or tenderness in abdomen. Pain on coughing. April 18, report on urine: no blood cells, a very few pus cells, and some bladder epithelium. Evacuated to England.

Case 41.—Pte. T. W. E., under the care of Major West. Shell. Wounded April 24, 1917. Wound left side, back of loin. Arrived at base, May 6. May 7, a secondary hæmorrhage from wound, which ceased. Repeated on May 8. Operation, May 8. The eleventh and twelfth ribs were broken, but pleural cavity apparently not opened. (No chest signs had been present.) There was a colostomy opening discharging fæces into wound. Lower pole of spleen lacerated and sloughy. Bleeding was seen to

come from the kidney, the lower pole of which had stitches in it. Kidney removed. Before operation, clear urine was drawn from the bladder. The notes of this patient were lost in transit between the clearing station and the base. The patient died three days later from sepsis. The injury to the kidney was confined to the lower pole, which was foul and sloughy.

Case 42.—Sergt. H. F. L., under the care of Major West. Shell. Hit Jan. 2, 1917. Entrance wound, left side, posterior axillary line. Exit, right side, mid-axillary line, just above crest of ilium. Abdomen soft. Hæmaturia. Paraplegia. Pulse had varied from 100 to 120 during first twenty-four hours. Later, came down to between 92 and 100. Catheterized every six hours. Some urethritis. Cystitis. Jan. 8, *x* rays showed fracture of body of first lumbar vertebra. Blood present in urine, an ounce or two of blood-clot in each pint. A second skiagram showed a piece of metal on left side, 2½ inches from mid-line, below twelfth rib, probably in kidney. On right side another piece, deep in muscles. Also fracture of second lumbar vertebra at junction of pedicle and lamina on left side. Pieces of loose bone. In region of left kidney, a deep swelling. Dullness over left lower ribs below axilla. Jan. 13, much vomiting for the last few days. Died, Jan. 15.

Post-mortem made by Capt. Henry.—Lower half of first lumbar vertebra and upper half of second lumbar vertebra in region of transverse processes and laminæ have been smashed by missile, which has passed obliquely through the bony canal from side to side, tearing dura mater, through which cauda equina is prolapsed. Large suppurating hæmatoma around left kidney. Extensive laceration of middle of outer border of left kidney. (See *Fig.* 193.)

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[1] Bowlby, *Brit. Jour. Surg.*, 1916, iii, No. 11.
[2] Bashford, *Ibid.*, 1917, iv, No. 15.
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[4] Fullerton, *Ibid.*, 1910, July 9.
[5] Fullerton, *Brit. Jour. Surg.*, 1913, i, No. 2.
[6] Tremolières et Caussade, *Ann. de Méd.*, 1917, iv, No. 1.
[7] Fullerton *Brit. Jour. Surg.*, 1916, iv, No. 14.
[8] Crymble, *Ibid.*
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ILLUSTRATIONS OF WAR SURGERY.

(*Continued from Vol.* iv, *page* 63.)

[Under this heading we propose to publish during the War a series of drawings illustrative of military surgery in its various aspects. The BRITISH JOURNAL OF SURGERY is indebted to Surg.-Gen. Sir George H. Makins and Surg.-Gen. Sir Anthony Bowlby for their help in the selection of cases and for their clinical remarks on certain of those selected. The notes, supplied by various officers of the Royal Army Medical Corps, under great pressure of work, are necessarily brief. The drawings have been made by artists specially commissioned for the purpose.]

Bullet Marks upon the Skin of the Abdominal Wall: with a Note on the question of the Heat retained by the Spent Bullet. (By SURG.-GEN. SIR GEORGE H. MAKINS and LIEUT.-COL. PINCHES.)

The drawing, *Fig.* 200, represents appearances seen on the abdominal wall of the umbilical region of a man under the care of Lieut. Fergusson.

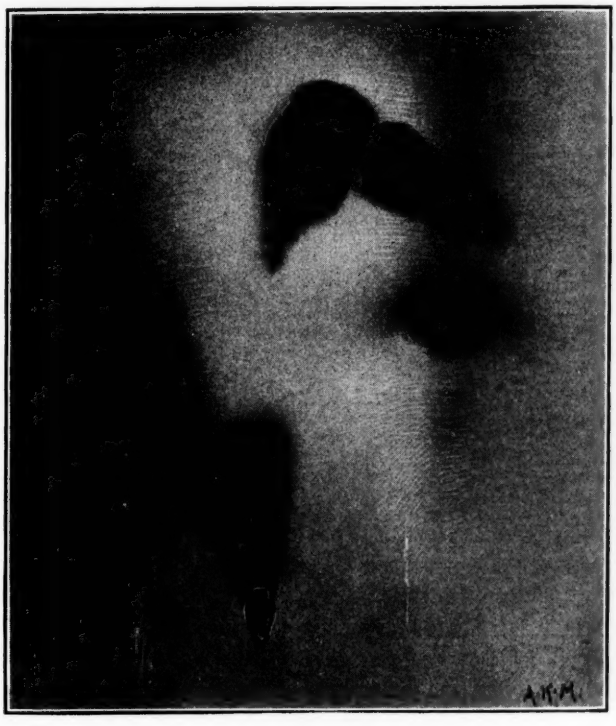


FIG. 200.

The history of the case was as follows: Three days before admission the patient received two shrapnel-case wounds, one in the buttock, the second in the leg, neither of them being severe.

He fell on his back into a ditch, and while lying there "felt a sharp burning pain over the abdomen: he drew up his shirt and removed a bullet from between it and the skin. The bullet was not hot when he touched it."

When seen on the third day, five apparent impressions of the bullet were discovered, rosy-red in colour. At the upper end of the broad one a scab following the drying up of a vesicle was seen, while at the tip of the innermost of the three lower impressions a vesicle containing serum was still present.

The drawing has been made from a sketch depicting the exact size of the 'burns,' taken at the time by Lieutenant-Colonel Pinches, who was then acting as my A.D.C.

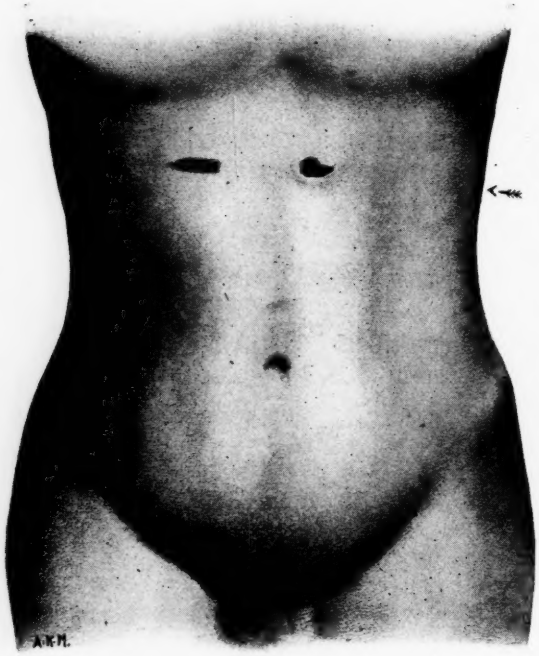


FIG. 201.

The illustration bears upon the vexed question as to the temperature of a recently-fired bullet. I have occasionally seen red marks suggesting the outline of a bullet upon the body, but have never met with a case in which such circumstantial evidence was offered. Naturally, the retention of a spent bullet between the skin and the patient's clothing is a rare occurrence, while if such bullets are met with, it is usually only after they have undergone the cooling process of passing through the body.

The evidence must be accepted or rejected by individual judgement, the appearances presented were in my own opinion those of a burn, and I see no reason to disbelieve the history of its occurrence given by the patient. [*Ref. No.* 199.]

Fig. 201.—Represents a similar case, except that in this instance the bullet had traversed the tissues. This patient also was under the care of Lieutenant-Colonel Pinches, who has kindly given the particulars. The bullet entered in the eighth intercostal space of the left side in the anterior axillary line, and emerged in the epigastrium. The patient felt something burning him, and got up from the ground; he put his hand under his shirt and removed a bullet from above the pubes. In this instance also the outline of the red mark closely corresponds to that of the bullet, and it is difficult to believe that it does not correspond with the primary position taken up by the spent bullet. [*Ref. No.* 200.]

Bomb Wound of Face.

The drawing, *Fig.* 202, illustrates an extreme instance of ' fine tattoo ' of the skin of the face surrounding a wound leading down to a fracture of the mandible. The patient was under the care of Dr. Kazanjian, in the ' oral '

FIG. 202.

department, where the fracture of the jaw was being treated. This beautiful drawing of Mr. Maxwell's, taken with those published in foregoing numbers of THE JOURNAL OF SURGERY, may be said to complete the depiction of the varying degrees of minor injuries to the face resulting from bomb wounds.*

* Vol. iii, *Fig.* 37, p. 114 : " A patch of small areas gives the appearance of a coarse ' tattoo.' " *Fig.* 85, p. 267 : Multiple shell wounds. *Fig.* 167, p. 503 : Bomb wound of face.

A CONTRIBUTION TO THE PATHOLOGY OF PROJECTILE FRACTURE OF LIMB BONES.

By Major E. K. MARTIN, R.A.M.C., and Captain G. F. PETRIE, R.A.M.C.

Projectile fractures observed during this war have created new problems, owing partly to the frequent complexity of the lesions, and partly to the coincident infection, of a type rarely encountered under civil conditions. They have given far greater opportunities than have occurred hitherto for the study of the interaction of bacteria and bone. It is the purpose of this communication to illustrate these reactions as they occur during the first six weeks after infliction of the wound, and to show that they may be modified not merely by morbid changes incidental to the local trauma, but by circumstances remote from and independent of the primary injury to the bone. These conditions, whether local or remote, and whether acting singly or in combination, tend to produce a variety of types of infection, ranging from the unrestrained bacterial invasion of a damaged bone, to the deviations from this type brought about by surgical intervention. In the absence of clear conceptions of the progressive changes within the bone which lead either to healing or to a state necessitating radical surgical interference, the foundations of rational treatment do not exist.

The material on which this paper is based was derived from thirty-two patients at a base hospital in France, and comprises a variety of infected fractures, chiefly of the cancellous tissue, but also of the shaft, of long bones. The cases were taken at random as opportunity offered, and of necessity include a considerable proportion which were not on the road to recovery. In addition to clinical observation of each case, the fracture and adjacent soft parts were dissected, and bacteriological examinations were made from serial sections of the bone. The results have shown that the variables contributing to form each type of infected fracture are such as to make it desirable to accumulate for examination a sufficient number of examples to allow of a grouping of the cases for statistical analysis. The importance of this lies not only in confirming isolated or limited findings, but in tracing the stages through which infection of bone passes, and in attempting to correlate clinical states with the nature and degree of the infection. Although the observations recorded here do not altogether reach this standard, they have indicated certain lines along which the problem may be attacked, and have led to a number of reasonably definite conclusions.

The scope of the inquiry is indicated in the following scheme :—

I. Mechanical Accompaniments of Projectile Fracture.
- Bruise.
- Fissure.

II. Methods of Investigation.
Nature of material.
Details of technique.
Recording of results.
III. Spread of Infection from Fracture.
Varieties of bacteria isolated from bone.
Factors influencing penetration of bone by bacteria :—
Structural and anatomical variety of bone.
Extent and degree of injury.
Types of bacteria.
Infection of the surrounding soft parts.
Diminution of blood-supply.
Surgical treatment of wounds.
Time.
IV. Extension of Infection along Fissures.
V. Conclusions.

I. MECHANICAL ACCOMPANIMENTS OF PROJECTILE FRACTURE.

The varieties of projectile fracture are so well known that formal description of them is superfluous. Two features, however, stand out so prominently as to repay detailed examination—namely, the bruise which invariably accompanies gunshot injury of bone, and the fissures which commonly do so.

Bruise of Cancellous Bone.—When a missile strikes cancellous bone, a bruise is produced at the point of impact, whether the outer compact layer is broken or remains intact. Bruising is met with under three conditions: (1) Direct bruise round the track of a penetrating missile; (2) Direct bruise without penetration; (3) Indirect or contrecoup bruise in the same or an adjacent bone.

1. *Direct Bruising round a Missile.*—Examples are shown in *Figs.* 203, 204, and 205. In *Fig.* 203, the periosteum has been removed from the back of the tibia to show the bluish appearance of the bruise as seen through compact bone. The articular cartilage is stained by the blood in the joint except at the site of the bruise. In the transverse section of the same tibia, taken immediately below the embedded shrapnel ball, the characteristics of a typical bruise are seen—the dark-red colour of the effused blood filling the cancellous spaces, the outline concentric with the foreign body, and the sharp line of demarcation, broken only by a slight tendency to radiation at the junction with the normal bone. This bruise was sterile on culture, and the whole specimen demonstrates the type colours of a recent aseptic trauma.

Fig. 205 represents a horizontal transverse section of one femoral condyle from a resection of the knee-joint for multiple shell-wounds. The joint contained a sterile blood-effusion. The figure shows clearly the sharp limitation of the bruise concentric with the shell fragment, and the characteristic absence of fissures radiating from the shell site. Several such bruises have been examined under a dissecting microscope, and the absence of even the smallest cracks in the trabeculæ confirmed.

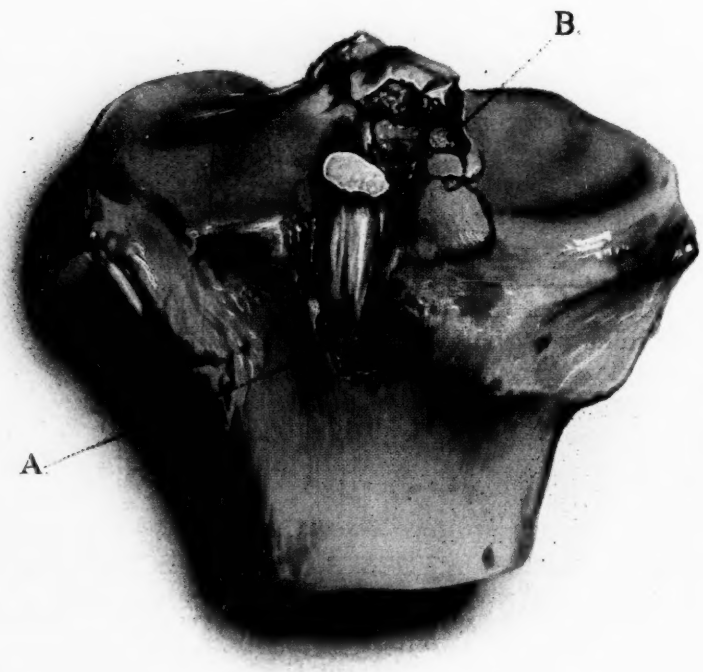


FIG. 203.—Upper end of tibia from behind, showing bluish appearance of bruised cancellous bone as seen on the surface after removal of periosteum. *A*, Entry wound. *B*, Shrapnel ball.

FIG. 204.—Transverse section of same tibia immediately below shrapnel ball, showing appearance of aseptic bruise two days after injury.

Figs. 206 and 207 show the extent of the bruising up the shaft from a penetrating wound of the femoral condyle accompanied by fissuring.

Fig. 208 (*Case* 12) shows a bruise which was produced by a minimal tangential blow. The articular cartilage was chipped, but the subjacent compact layer of bone was not even cracked.

The colour of a bruise fades rapidly on exposure to the air or immersion in water. During an operation, an underlying bruise is easily recognized by the bluish colour on the surface of the overlying bone or articular cartilage. When exposed, it is a much darker red than normal cancellous tissue.

2. *Direct Bruising without Penetration.*—Direct bruising of the condyles of the femur without fracture has been found associated with extensive flesh wounds where large shell-fragments of low velocity have opened the knee-joint and necessitated amputation for suppurative arthritis.

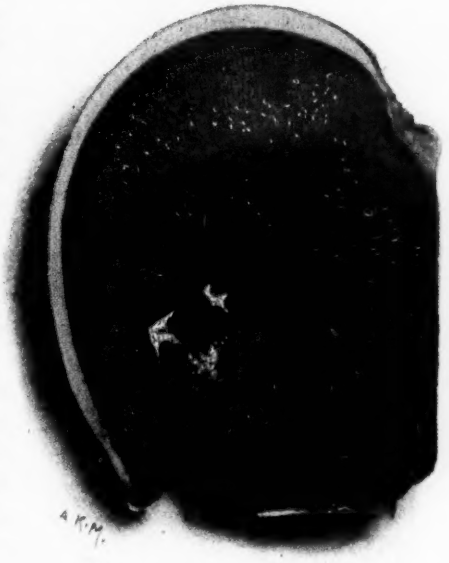


FIG. 205.—Section of femoral condyle with embedded shell-fragment, showing bruise without fissuring; day following injury.

3. *Indirect or Contrecoup Bruising in the Same or an Adjacent Bone.*—*Fig.* 209 shows a direct and indirect bruise in the same bone. Z^1 is the direct bruise round the fracture, separated by a zone of undamaged bone from Z^2, the indirect bruise produced by impact of the head of the humerus against the scapula.

Fig. 211 shows the extent of an indirect bruise which was produced in an otherwise uninjured tibia as a contrecoup effect from a fracture of the lower end of the femur (*Fig.* 210). This bruise showed on the upper surface of the tibia as a bluish discoloration round the spine, but no crack of the latter or of the articular cartilage existed.

Bruising of the marrow of the shaft similarly accompanies fracture. Owing to the thickness of the surrounding compact layer, it can only be seen on section. Where fissures exist, the bruising always extends up to, and may extend beyond, their limits.

Fissures.—These are found in both the compact bone of the shaft and the cancellous bone of the extremities, though much more commonly in the former. They can, in fact, be considered as a regular accompaniment of comminution, and frequently extend for long distances—10 cm. or more—up and down the shaft from the point of primary injury, or from the site of an embedded foreign body which has not produced a complete fracture.

Fissures are of two kinds—those which remain open, and those whose walls spring back into apposition as soon as the force of the blow is exhausted. The latter are found only in the elastic compact bone of the shaft, and unite

without incident, in contrast with the open fissures, which play an important part in spreading infection. They may be due either to the direct effect of the missile itself, in which case the fissure commences in the fracture and ends blindly in the bone, or to the indirect effect of the fall or muscle-twitch which follows the mechanical stimulus. In the latter case the fissure does not communicate at any point with the original bone wound, and is apt to assume the

FIG. 206.—Lower end of femur removed by amputation 48 hours after injury. Embedded shell-fragment, with surrounding fissures.

FIG. 207.—Longitudinal section of femur shown in *Fig.* 206. Extent of corresponding bruise.

spiral form associated with simple fracture; it is, in fact, a minor degree of the indirect complete fracture which not uncommonly accompanies direct partial fracture of another part of the bone, or occasionally may even be associated with a simple flesh wound of the limb.

All fissures in cancellous bone behave as open fissures. Apart from extreme comminution they do not often occur, unless prolonged from the

shaft, or unless a projecting portion of cancellous tissue is separated from the main bone by a perforating injury.

As a rule, a missile which penetrates the articular end of a bone, and remains embedded, cuts a tunnel but very little larger than itself, and comes to rest in a closely-fitting bed of bruised bone (*Fig.* 205). If a longitudinal section of such a tunnel is examined under a low power of a stereoscopic dissecting microscope after removal of the débris with which it is filled, the wall is seen to be sharply defined, the trabeculæ lining it being flattened by the pressure of the missile, while those in the immediate neighbourhood show no disturbance.

II. METHODS OF INVESTIGATION.

Nature of Material.—There are three sources from which material can be obtained: (1) Fragments of bone removed at operation; (2) Amputated limbs; (3) Autopsy.

1. Fragments of Bone Removed at Operation.—(*a*) *Small Fragments:* Cultures from bones were never made at operation, on account of the difficulty of carrying out an adequate bacteriological technique, and of the uncertainty of reaching the limits of infection in a living bone. (*b*) *Large Fragments:* The portions of bone removed in the resection of joints were found suitable for studying the spread of infection in cancellous tissue.

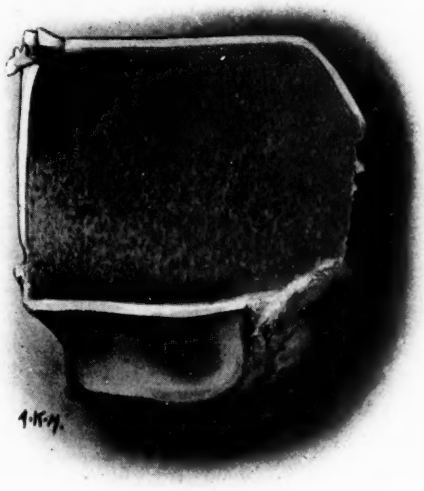


Fig 208.—*Case* 12. Coronal section of astragalus from amputation; 2½ days after injury. Bruise from minimal wound of articular cartilage without fracture of bone.

2. Amputated Limbs. — These were chosen as the principal source of material, for two reasons: (*a*) Because they are the most accessible source of fresh material; (*b*) Because it seemed probable that from them the processes at work in bones which ultimately unite might be reconstructed.

In order to obtain trustworthy data from the bacteriological examination of bones, it is essential that they should be examined immediately; or if this is impracticable, that steps should be taken to inhibit the growth of organisms which always follows the removal of any tissue from the body, and which makes it impossible to draw valid conclusions as to the conditions obtaining at the time of amputation. Post-mortem growth is illustrated by *Cases* 1, 2, and 3, Appendix I.*

3. Bones Removed at Autopsy.—In consequence of the liability to post-

* In order to avoid undue interruption of the narrative, detailed accounts of some of the cases have been collected in Appendix I, p. 328.

mortem growth, investigation of bone removed at autopsy has been confined to two cases in which no delay occurred in obtaining the material. Even if the material is taken immediately after death, the results do not necessarily correspond to those found in patients who ultimately recover; for where death is preceded by a gradual failure of the circulation, bacteria may grow as saprophytes throughout the bone during the terminal phase of the illness. In such a case the bacterial invasion is in reality a post-mortem phenomenon occurring during life (see *Cases* 4 and 5, Appendix I).

Details of Technique.

Procedure at Operation.—Under the anæsthetic a swab is taken from the wound as close to the fracture as possible; 10 c.c. of blood are withdrawn from a vein for cultural purposes; and if a joint is involved, a sample of the effusion is obtained by puncture away from the wound, after sterilization of the skin. The bone when removed is rapidly cleaned and put into ice, in which it remains until all preparations for investigation are complete.

Technique of Taking Bone Cultures.—After making a smear from the fracture, the whole bone is flamed with a blowpipe, and fixed in a vice which has previously been sterilized in the same way. Transverse sections are then made at measured intervals* with a flamed hack-saw, commencing at the end away from the fracture. The face of the section from which cultures are to be made is lightly seared, and pieces are scooped out with a *dry* sterile gouge. Before each successive transverse section, the bone and vice are lightly heated again with the blowpipe or searing iron.

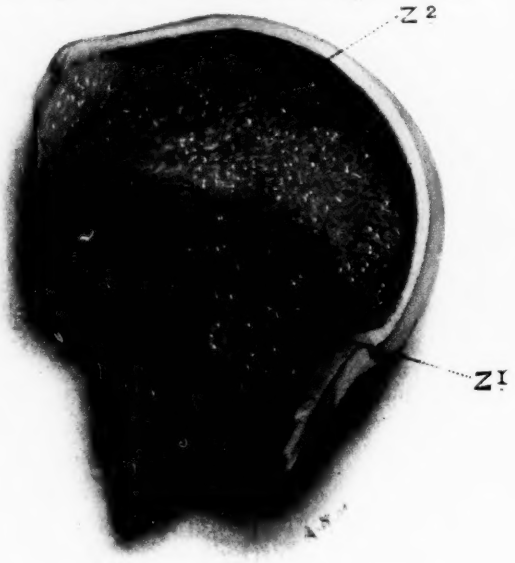


FIG. 209.—Section of head of humerus removed by resection 5 days after injury. Z^1, Direct bruise extending from fracture. Z^2, Indirect bruise from shock against scapula.

Each of the fragments removed by the gouge is about the size of a pea. One is inoculated into a serum-broth tube, for aerobic cultivation; the other into a short, stout culture tube containing broth, fitted with a solid glass rod flattened at the lower end for the purpose of grinding up the bone fragment as far as possible; from this suspension anaerobic cultures are prepared, and the tube itself is also incubated as a control upon the aerobic cultures. Anaerobic cultures are made into tubes of broth and milk media covered with a layer of liquid paraffin. The broth tubes contain small pieces of coagulated

* Unless sections are taken at frequent and regular intervals throughout the bone, the limit of infection cannot be determined with accuracy. Experience has shown that an interval of 2 cm. is the most suitable.

white of egg to indicate the presence of proteolytic anaerobes. If marked proteolysis occurs, a subculture is made into the same egg-broth medium grown aerobically, to test whether the digestive action may not be due to facultative anaerobes. The flora of the aerobic and anaerobic cultures are compared by making fresh and stained preparations, and by plating on serum agar and MacConkey agar. The aerobic colonies are picked off and identified. Comparison of the aerobic and anaerobic growths makes it possible to determine the presence of strict anaerobes. Anaerobes, when present in the bone fragment implanted in the primary *aerobic* broth-culture, are frequently found to have grown freely, especially in mixed cultures, their growth being aided

FIG. 210.

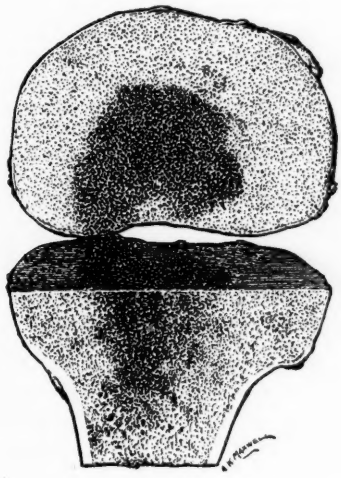


FIG. 211.

FIG. 210.—Shell fracture of lower end of femur.

FIG. 211.—Indirect or contrecoup bruise of upper end of tibia without fracture. Produced by blow on femur shown in *Fig.* 210. Sterile on culture.

by the layer of bone fat which forms on the surface. The complete identification of anaerobes was not undertaken, but the presence of ***B. perfringens*** was noted when the anaerobic milk-cultures presented the typical appearance of 'stormy fermentation'—that is, a clot of casein torn up by gas—and when, in such a culture, stout Gram-positive, non-motile, non-sporing, anaerobic bacilli were found.

Where necessary, smears of the bone samples are taken for microscopical examination.

There are two possible sources of error in the technique : (1) Overheating of the bone ; (2) Contamination by bone dust from the saw.

1. To check overheating, a thermometer was placed in a tibia, and the bone flamed with considerably more vigour than that necessary to ensure

surface sterilization. The thermometer rose from 17·5° C. to 26·5° C. In practice there has been no reason to suspect any error from this source.

2. Contamination is guarded against by making transverse instead of longitudinal sections, by commencing at the end farthest from the wound and therefore the least heavily infected, by searing each surface immediately before taking the scoop, and by flaming bone and vice between successive sawings. In the earlier cases sterile liquid paraffin was allowed to drip on to the saw-blade; this had the effect of greatly diminishing the dust, and causing it to adhere to anything it touched, but was afterwards discarded as superfluous.

In spite of the refractory nature of the material examined, accidental contaminations were met with in only 6 per cent of the aerobic cultures. As a rule these could easily be recognized as such, and in practice did not hamper the deductions which could be drawn from the cultural results.

Controls.—Cultures were taken from the blood, and, where possible, from uninjured bone, for the reason that in an established streptococcal septicæmia the organism present in the blood can be recovered both from uninjured bone and from the damaged bone beyond the limits of local penetration.

The room in which the investigations were carried out was on a medical floor, and had never been used as a surgical ward; aerial contamination of the cultures by pyogenic organisms derived from septic wounds can therefore be excluded.

Recording of Results.—After taking samples for culture, each section of bone is put aside in order, and from these a diagram is reconstructed to scale later. It is important to preserve these sections for future reference, and to clean them thoroughly in order to trace minute fissures concealed by the periosteum and to obtain more precise measurements.

The following method has been found useful for rapidly cleaning sections of bone in order to study points of detail: Remove soft parts, and place in 50 per cent liquor sodæ chlorinatæ (B.P.) for twelve hours. Immerse in water at 80° C. for fifteen minutes. Replace in liquor sodæ chlorinatæ for two periods of half an hour each, with alternate washings in water at 80° C. Bleach in H_2O_2 for twenty-four to forty-eight hours. Immerse in rectified spirit, and dry.

Each transverse section is traced on a glass plate, from which the tracing is transferred to paper, and a note is made of the colour and appearance of the bone at the level of section. Bruising is indicated on the diagram by darker stippling. The levels of section are numbered in sequence away from the fracture for convenience of reference, although they are actually cut in the reverse order (see TECHNIQUE).

The direction, up or down, of each bacteriological sample is indicated on the diagram representing the whole bone, its size and position being defined by the tracing.

A centimetre scale is attached to the diagrams, but owing to an obliquity of some of the sections, which has not been reproduced, and to the difficulty of estimating the depth of each scoop, there is an occasional error of a fraction of a centimetre in the distance of a sample from the fracture. For the sake of uniformity this has been neglected, and measurements have been given to a millimetre in all cases.

The bacteriological findings are represented by the following conventional signs :—

Growth resulting from direct penetration of organisms from the fracture.

Growth of septicæmic origin.

Sterile.

Other conventional signs used are : A = Main fracture. A^1 = Fissure extending from main fracture. B = Foreign body.

For the permanent recording of colour, the most suitable medium is a good water-colour sketch. This must be made as quickly as possible, on account of the rapidity with which the colours of fresh bone change. The Kaiserling method, in our experience, has the limited advantage of differentiating bruised from normal bone, but has proved inadequate to preserve the natural colours. Klotz and Maclachlan's modification of the Jores method gives better results.*

III. SPREAD OF INFECTION FROM THE FRACTURE.

Within the time limits of this investigation—that is, the first six weeks after infliction of the wound—infection of bone is met with in two forms, penetration by organisms without suppuration, and spreading suppurative osteomyelitis. For this reason the term infection is used in this paper to imply the presence of bacteria in bone as demonstrated by culture, without reference to their fate or to the reactions they excite. Since pathological states intermediate between these two stages of infection have not been observed, we have employed the term penetration to signify a demonstrable progression of bacteria through bone away from a fracture. The term does not imply the co-existence of inflammation.

Penetration has proved to be the chief manifestation of infection in the material examined, to the extent that only one instance (*Case* 22) of spreading suppurative osteomyelitis has been met with out of 37 bones investigated. The rarity of suppurative osteomyelitis is due to the fact that the missile itself establishes some drainage of the bone simultaneously with the implantation of the infective agent—that is, the infection is from the first an open one, in contrast with the closed infection of osteomyelitis as met with in civil experience.

Varieties of Bacteria Isolated from Bone.—With few exceptions, the bacteria isolated from freshly examined material fall into four groups, streptococci, staphylococci, anaerobic bacteria, and coliform bacilli. The frequency of occurrence of these groups is shown in *Table* 1, in which also will be found data relating to the bacterial content of wounds and of joints during a comparable period of their surgical history. The figures for wounds have been reduced from data published by Captain A. Fleming (" On the Bacteriology of Septic Wounds," *Lancet*, September 18, 1915).

* Adami and Judah, *International Association of Medical Museums*, Bull. v, June 1, 1915.

Table 1.—Showing the Frequency of Occurrence of Bacterial Groups in Bones, Wounds, and Joints, expressed as Percentages (Actual Numbers in Brackets).

Infection	Bones	Wounds (*Fleming*)	Joints
Streptococcus..	33·6 (36)	35·4 (177)	55·5 (15)
Staphylococcus	23·3 (25)	15·0 (75)	25·8 (7)
Anaerobes ..	23·3 (25)	34·6 (173)	7·4 (2)
B. coli ..	19·6 (21)	14·8 (74)	11·1 (3)
Totals	100 (107)	100 (499)	100 (27)

Table 2.—Giving Details of the Source of Bacteria Isolated from the Material Analysed in *Table* 1.

Source	Streptococcus	Staphylococcus	Anaerobes	B. Coli
Femur ..	8 bones gave 15 cultures	4 bones gave 6 cultures	6 bones gave 12 cultures	5 bones gave 13 cultures
Tibia.. ..	5 bones gave 16 cultures	5 bones gave 8 cultures	5 bones gave 7 cultures	3 bones gave 4 cultures
Fibula ..	—	1 bone gave 1 culture	—	1 bone gave 1 culture
Os calcis ..	—	—	1 bone gave 2 cultures	—
Humerus ..	1 bone gave 2 cultures	3 bones gave 3 cultures	2 bones gave 2 cultures	1 bone gave 1 culture
Radius ..	—	2 bones gave 4 cultures	1 bone gave 1 culture	1 bone gave 1 culture
Ulna	1 bone gave 3 cultures	2 bones gave 3 cultures	1 bone gave 1 culture	1 bone gave 1 culture

Note on Tables 1 *and* 2.—The cultures from bones were derived from 59 samples taken from 29 bones (19 patients) giving a pure or mixed growth. The 29 bones examined were : femur, 10 ; tibia, 7 ; fibula, 2 ; os calcis, 1 ; humerus, 4 ; radius, 2 ; ulna, 3. The material was in every case removed at operation and examined fresh, and does not include specimens from cases of streptococcal septicæmia.

The results for joints include only those cases in which not more than two bacterial varieties were isolated, since mixed growths similar to those found in septic wounds are usually obtained from cases of extensive injury where the joint forms part of the primary wound, and where consequently there is no question of selection of the originally implanted bacteria.

Reviewing these results, it would seem that selection of the soil bacteria inoculated at the time of entrance of the missile takes place in the tissues, the process of selection affecting particularly the group of anaerobes. Thus, in wounds providing a nidus for growth of micro-organisms in muscle, anaerobes form a large proportion of the bacterial contribution, the proportion decreasing in bones, and still more so in joints. It may be that in the case of joints the suitability of the effusion as a culture medium is an additional factor determining the selection. These considerations are essential to the study of the sequence of infection in cases of fracture involving joints.

It has already been noted, and the point deserves emphasis, that in cases of streptococcal septicæmia, the streptococcus can be isolated from fractured bones beyond the limit of local penetration, and even from uninjured bones. A partial examination without a blood-culture control, made in ignorance of this fact, might easily lead to erroneous interpretations regarding the spread of infection. It is naturally difficult to decide whether the streptococcus in these cases merely resides in the blood-vessels of the bone marrow, or whether in addition some local multiplication in the perivascular tissue has taken place. The constancy with which positive cultures are obtained renders possible the latter supposition (see *Case* 13, and *Cases* 5, 15, 16, Appendix I). The results obtained in *Case* 15 suggest that, in spite of general septicæmic invasion of a bone, a progressive extension of streptococcal infection from the site of injury is demonstrable from the number of positive cultivations in a variety of media, dependent on the number of cocci present in the material implanted in the culture tubes. The culture results in this case are tabulated below.

Table 3.—*Case* 15 (*Fig.* 256).

Specimen taken for culture	Situation relative to fracture	Growth in		
		Aerobic broth	Anaerobic broth	Anaerobic milk
Femur 1	Lower fragment : in fissured portion	+	+	+
,, 2	Lower fragment : at limit of fissure	+	+	+
,, 3	Lower fragment : 2·1 cm. beyond fissure	+	0	+
,, 4	Lower fragment : 7·8 cm. beyond fissure	+	0	0
,, 5	Upper fragment : 3·4 cm. from fracture	+	0	0

+ = Growth of streptococcus.

The *B. pyocyaneus* and *B. proteus* were not often encountered, the former having been found in only 3 samples out of 112 yielding cultures (2·6 per cent) —see *Case* 17 ; and the latter in 2 out of 112 samples (1·7 per cent)—see *Case* 14.

From two bones in which necrosed comminuted cancellous tissue was present on the surface of the fracture, a number of aerobic bacteria, probably associated with putrefaction, and giving unfamiliar reactions, were isolated. As this phase of infection is not typical of the series of cases investigated, an account of the bacteriological findings need not be given.*

Examples of Penetration through Normal Bone.—The simplest conditions under which penetration of bone can be studied are those obtaining at the end of an open amputation stump where the patient is in good

* Notes on the cultural reactions of staphylococci and *B. coli* isolated from bone will be found in Appendix II.

condition, the trauma confined to the actual surface of section, the blood-supply intact, and the infection limited to the ordinary pyogenic organisms found in wounds.

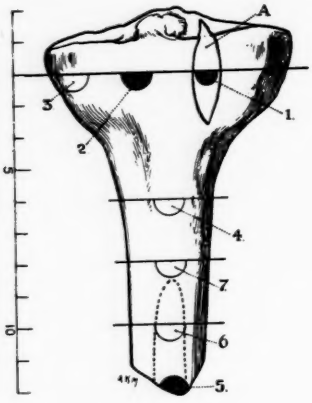


FIG. 212.

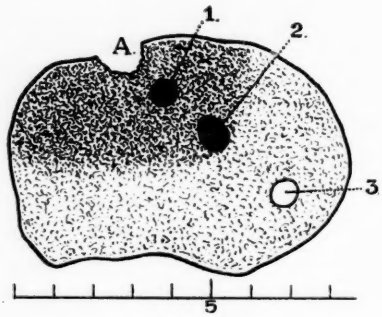


FIG. 213.

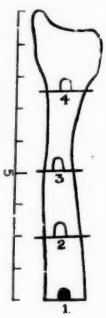


FIG. 214.

FIG. 212.—*Case* 7. Tibia from flapless amputation exposed to infection about 10 days. Organisms confined to cut surface. Gutter wound of anterior aspect of upper end has allowed penetration of organisms to 2 cm.

FIG. 213.—*Case* 7. Transverse section of tibia at level of (1), (2), (3). A, Fracture.

FIG. 214.—*Case* 7. Fibula from flapless amputation exposed to infection for about 10 days. Organisms confined to cut surface.

Table 4.—*Case* 7.

SPECIMEN TAKEN FOR CULTURE	DISTANCE FROM LESION	AEROBIC BACTERIA*	ANAEROBIC BACTERIA*
Tibia 1	0·5 cm.	Streptococcus Staphylococcus Yeast	+ (including *B. perfringens*)
„ 2	2·0 „	Streptococcus	0
„ 3	4·5 „	0	0
„ 4	2·5 „	0	0
„ 5	Surface	Streptococcus Staphylococcus *B. mycoides* Yeast	+ (including *B. perfringens*)
„ 6	1·5 cm.	0	0
„ 7	3·5 „	0	0
Fibula 1	Surface	Staphylococcus	—
„ 2	2·0 cm.	0	—
„ 3	4·1 „	0	—
„ 4	6·5 „	0	—
Knee-joint at amputation	..	Streptococcus	0
Blood from vein at amputation	..	0	—

Exposure of bone to sepsis.—About 10 days.
Amputation.—June 2, 1916, 11.20 p.m.
First culture taken from bone.—June 3, 12.40 a.m.
Last culture taken from bone.—June 3, 2.5 a.m.
Order of cultures.—Fibula : 1, 2, 3, 4. Tibia : 3, 2, 1, 4, 7, 6, 5.

* In this and the following tables, + = Growth of anaerobes ; 0 = Absence of growth ; — = Culture not made.

Case 7.—Lieut. A., age 25. [*Ref. No*, 202.]
Lesion.—Gutter of articular border of tibia, involving knee-joint.
Clinical History.—Flapless amputation 12 cm. below knee-joint at casualty clearing station for bomb wounds of leg. Re-amputation above knee at base hospital for streptococcal arthritis of knee (*Figs.* 212, 213, 214).

These bones show that in amputation through normal shaft under the simplest conditions, organisms do not penetrate far below the surface. The invaded bone is, however, softened, and this process of penetration by organisms is possibly associated with the formation of the superficial sequestrum which frequently separates at a later date. (See *Case* 6, Appendix I, for similar conditions in cancellous tissue, and *Case* 8, Appendix I, in which the conditions as regards the bone were identical, but in which drainage of the soft parts was not sufficiently free to allow of saving the limb.)

FACTORS INFLUENCING PENETRATION OF BONE BY BACTERIA.

Analysis of the material examined shows that a number of factors operate to influence the process of penetration, and that they are frequently found in varying combinations. The discussion of the factors which have been kept in view as possibly influencing penetration is arranged as follows :—

1. Structural and anatomical variety of bone.
2. Extent and degree of injury.
3. Types of bacteria.
4. Infection of the surrounding soft parts.
5. Diminution of blood-supply :
   - *a*. Local : Interruption of the main artery of the limb ; Interruption of the chief artery to the bone ; Interruption of the medullary artery at the site of fracture.
   - *b*. General : Death ; Hæmorrhage following operation ; and Secondary hæmorrhage.
6. Surgical treatment of wounds.
   - *a*. Penetration in fracture with untreated bone : Early ; and Late.
   - *b*. Penetration with obstruction of drainage : (i) Influence on penetration of inadequate drainage of soft parts ; (ii) Influence on penetration of inadequate drainage of bone.
   - *c*. Penetration in presence of undrained fissure.
   - *d*. Penetration in well-drained bone with reinforcement of sepsis from the soft parts.
   - *e*. Absence of penetration with free drainage of bone and soft parts.
7. Time.

1. **Influence of the Structural and Anatomical Variety of Bone.**—We have found no evidence that the marrow of the shaft differs materially in its reaction to penetration from the cancellous bone of the articular ends, nor has any difference been noted between individual bones.

2. **Influence of the Extent and Degree of Injury.**—In untreated cases, while the whole surface of the fracture is potentially a source of penetration, the actual track or resting-place of the missile is the most favourable

point of departure, on account of the presence of infected débris on the surface of the bone. If this is removed, there is no evidence that the subjacent bruise facilitates penetration.

3. **Estimate of the Power of Penetration possessed by each Bacterial Group.**—Since the frequency-data presented in *Table* 1 are based on the results of cultivating at various distances from the site of the fracture, they may be presumed to give an indication of the penetrating capacity of the invading bacteria. Direct evidence is obtainable by measurement of the extreme limit of penetration in a series of cases, and by taking an average for each group of organisms. This has been done, with the following results (three bones giving very mixed growths are excluded): (*a*) The average distance of penetration of the streptococcus in ten cases is 2·0 cm. (*b*) The average distance of penetration of the staphylococcus in ten cases is 1·5 cm. (*c*) The average distance of penetration of anaerobes in six cases is 0·8 cm. (*d*) The average distance of penetration of *B. coli* in three cases is 0·7 cm. The two sets of observations are mutually confirmatory, and justify the conclusion that they are an expression of the penetrating capacities of the bacterial groups concerned. *Cases* 9 and 10, Appendix I, illustrate the low penetrating power of *B. coli.*

It has not been possible to make an exact study of the anaerobes met with in bone, but it is apparent that the *B. perfringens* has less tendency to penetrate bone than other types of anaerobe. Thus, of 20 bones examined, out of 16 cultures growing anaerobes from the surface of the lesion, 8 yielded *B. perfringens* (50 per cent); while out of 29 cultures growing anaerobes at various levels, *B. perfringens* was present in 7 (24 per cent).

4. **Infection of Soft Parts.**—It is evident that penetration in fractured bone cannot be dissociated from the conditions as regards infection of the surrounding soft parts, since the primary lesion of the bone is an integral part of the wound, and is therefore liable to receive reinforcement of sepsis from inadequately drained recesses. This question is intimately connected with the influence of surgical treatment of the wound on penetration, and its further discussion here is unnecessary.

5. **Effect of Diminution of the Blood-supply.**—As in the soft parts, any considerable diminution of the blood-supply to bone is immediately reflected in an increased growth of bacteria, especially anaerobes. There are two conditions under which this occurs, namely: (*a*) Local diminution; (*b*) General diminution.

a. Local Diminution of Blood-supply.

i. *Interruption of the Main Artery of the Limb.*

Case 11.—Major S., age 33. [*Ref. No.* 206.]

Lesion.—Perforating high-explosive shell wound of elbow, with superficial fracture of under surface of coronoid process of ulna.

Clinical History.—Dec. 25, 1916, severe multiple wounds. Elbow track cleaned out at casualty clearing station, and brachial artery tied. Elbow remained normal till Jan. 16, 1917, when patient complained of severe pain in joint, which showed the physical signs of acute arthritis. Immediate resection of head of ulna and radius. Humerus intact, not interfered with.

Examination of Parts Removed, Jan. 16.—Under surface of coronoid process bare. No breach of cartilaginous surface of ulna. Capsule soft and infiltrated

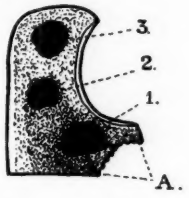


FIG. 215.—*Case* 11. Olecranon process removed by operation 22 days after injury. Temporary interference with blood-supply by ligature of brachial artery.

where attached to edge of coronoid process, and infection probably reached joint by this route (*Fig.* 215).

Table 5.—*Case* 11.

SPECIMEN TAKEN FOR CULTURE	DISTANCE FROM LESION	AEROBIC BACTERIA	ANAEROBIC BACTERIA
Ulna 1	In fissure	Streptococcus	0
,, 2	1·6 cm.	,,	0
,, 3	2·5 ,,	,,	0
Elbow-joint at operation	..	,,	0
Blood from vein, Jan. 12	..	0	—
,, ,, Jan. 21	..	0	—

Exposure of bone to sepsis.—22 days.
Resection.—4.0 p.m.
Bone in ice.—From 4.5 p.m. to 5.45 p.m.
First culture taken from bone.—6.10 p.m.
Last culture taken from bone.—6.21 p.m.
Order of cultures.—3, 2, 1.

Owing to the ligature of the brachial artery in the wound in this case, the blood-supply of this portion of the bone was temporarily interfered with, although at no time was there any serious inadequacy of the circulation through the forearm.

ii. *Interruption of the Chief Artery to the Bone.*—Two cases of wounds of the os calcis illustrate this point, the wounds and general condition of the patients being sufficiently similar to eliminate any other influence adequate to explain the discrepancy. The blood-supply of this bone is derived almost entirely from the posterior tibial artery. Where this artery was intact (*Case* 12), penetration was limited to the immediate neighbourhood of the fracture. Where the artery was divided (*Case* 13), penetration of organisms was found throughout the whole bone.

Case 12.—Lieut. L., age 22.
Lesion.—Perforating shell-wounds of ankle. Compound fracture of tibia, fibula, astragalus, and os calcis. Ankle-joint open. Astragalo-calcanean joint full of blood.
Clinical History.—Wounded Sept. 15, 1916, at night. Wounds packed with gauze at casualty clearing station. On arrival at base hospital, very ill, skin jaundiced, partly conscious. Amputation 15 cm. above malleoli on Sept. 18 at 11.0 a.m., two and a half days after infliction of wound. Death two hours later.
Clinical Picture.—Anaerobic toxæmia.

Examination of Foot, Sept. 18, 5.40 p.m.—Perforating wound at level of inferior tibiofibular joint, involving both bones, opening ankle, and grazing astragalus. This wound contained mud and cloth beneath the gauze pack. Separate perforating

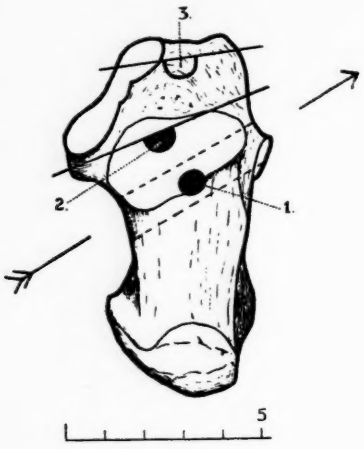


FIG. 216.

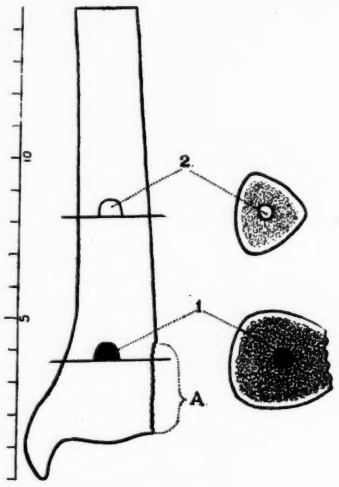


FIG. 217.

FIG. 216.—*Case* 12. Os calcis with perforating shell-track removed by amputation 2½ days after injury. Posterior tibial artery intact. Penetration to 0·5 cm.

FIG. 217.—*Case* 12. Tibia with gutter fracture, same limb as *Fig.* 216. Penetration to 1 cm.

wound of os calcis, with entry below posterior end of sustentaculum tali, and exit at peroneal spine. Soft parts of foot swollen, but not gangrenous. No gaseous cellulitis. (*Figs.* 216, 217, and 208.)

Table 6.—*Case* 12.

SPECIMEN TAKEN FOR CULTURE	DISTANCE FROM LESION	AEROBIC BACTERIA	ANAEROBIC BACTERIA
Tibia 1	1·0 cm.	Staphylococcus	+
„ 2	4·2 „	0	0
Calcaneum 1	Surface	0	+ (including *B. perfringens*)
„ 2	0·5 cm.	0	+
„ 3	1·8 „	0	0
Blood from vein at amputation	..	0	+

Exposure of bone to sepsis before amputation.—2½ days.
Bone in ice.—From 11 a.m. to 5.30 p.m.
First culture taken from bone.—5.40 p.m.
Last culture taken from bone.—6.30 p.m.
Order of cultures.—Tibia: 1, 2. Calcaneum: 3, 2, 1.

Note.—The bacillus isolated in pure culture from the blood and from Tibia 1 and Calcaneum 2 was a non-proteolytic anaerobe morphologically resembling *B. perfringens*, but differing from it in not producing the 'stormy fermentation' reaction in milk.

Case 13.—Lieut. R., age 41.

Lesion.—Multiple high-explosive shell wounds. Right foot: Anterior half shattered. Right leg: Perforating flesh wound 10 cm. above ankle, dividing posterior tibial artery. Right knee: Small penetrating wound, with shell fragment embedded in internal condyle of femur. Other minor flesh wounds.

Clinical History.—Wounded Oct. 22, 1916. Operation at casualty clearing station, Oct. 23, confined to cleaning all flesh wounds and disarticulation at right tarsometatarsal joint. Right knee not touched. Arrived at base Oct. 27. Temperature 102·4°, pulse 120. Right knee quiet. Amputation in lower third of thigh for streptococcal arthritis, Oct. 29, 11.25 a.m. Death Oct. 30, 5.30 a.m.

Clinical Picture.—Septicæmia.

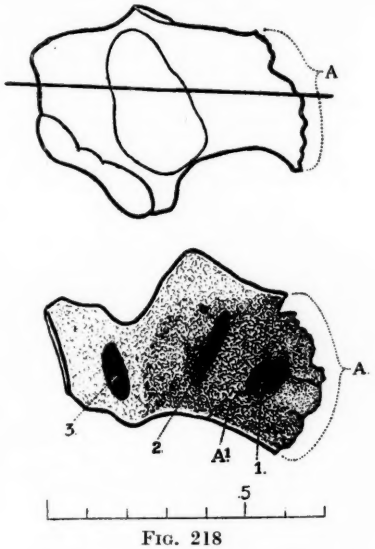


FIG. 218

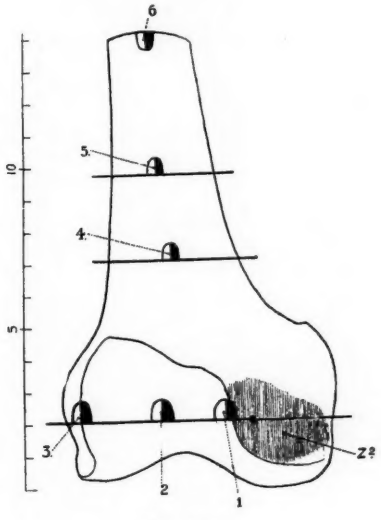


FIG. 219.

FIG. 218.—*Case* 13. Os calcis with shell wound of tuberosity removed by amputation 7 days after injury. Posterior tibial artery divided. Penetration of whole bone by anaerobes. (*Cf. Fig.* 216.)

FIG. 219.—*Case* 13. Lower end of femur removed by amputation 7 days after injury. Streptococcus in blood recovered from all parts of bone.

FIG. 220.—*Case* 13. Tracing of transverse section of femur shown in *Fig.* 219. Small shell-fragment with surrounding bruise. Streptococcus in blood recovered from injured and uninjured bone. Z^1, Soft bone probably infected from shell. Z^2, Hard bruised bone. Growth at (1) may be a local extension from shell.

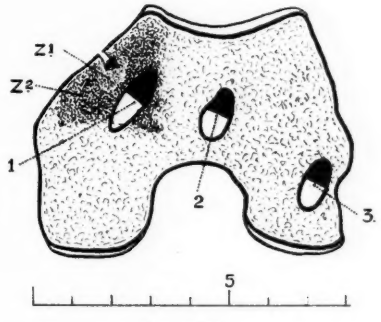


FIG. 220.

Examination of Limb, [Oct. 29.—Foot: Surface of amputation covered with brown exudation—superficial necrosis. Foul wound of heel, with fracture of tuberosity of os calcis. No gangrene or gaseous cellulitis. Leg: Septic tunnel through deep flexors, dividing posterior tibial artery. Knee: Skin puncture covered with small dry scab. Small hole in synovial membrane, through which the deeper part of the extra-articular track had become infected. Small shell-fragment embedded in anterior part of internal condyle at reflection of synovial membrane from bone to capsule. Surrounding bruise. Joint effusion, blood-stained. Os calcis and 14 cm. of femur examined for penetration by organisms. (*Figs.* 218, 219, 220.)

Table 7.—Case 13.

Specimen taken for Culture	Distance from Lesion	Aerobic Bacteria	Anaerobic Bacteria
Os calcis 1	In fissure	Streptococcus, coliform bacillus	+
,, 2	0·7 cm.	Streptococcus, coliform bacillus	+
,, 3	2·1 ,,	Streptococcus, coliform bacillus	+
Femur 1	0·5 ,,	Streptococcus	0
,, 2	2·5 ,,	,,	0
,, 3	5·5 ,,	,,	0
,, 4	5·5 ,,	,,	0
,, 5	8·0 ,,	,,	0
,, 6	12·0 ,,	,,	0
Tibia (control)	..	,,	0
Knee-joint, Oct. 29	..	,,	0
Blood from vein 3½ hours after amputation	..	,,	0

Exposure of bone to sepsis.—7 days.
Bones in ice.—From 11.45 a.m. to 5.30 p.m.
First culture taken from bone.—5.35 p.m. Last culture.—7.15 p.m.
Order of cultures.—Femur : 3, 2, 1, 4. 5, 6. Tibia. Os calcis : 3, 2, 1.

iii. *Interruption of the Medullary Artery at the Site of Fracture.*—The effect of this is seen in a more extensive growth of organisms in the fragment which is cut off from the medullary artery. (See also *Cases* 15 and 16, Appendix I.)

Table 8.—Case 14.

Specimen taken for Culture	Distance from Lesion	Aerobic Bacteria	Anaerobic Bacteria
Upper fragment 1 ..	In fissure	Streptococcus	0
,, ,, 2 ..	1·5 cm.	,,	0
,, ,, 3 ..	3·5 ,,	0	0
,, ,, 4 ..	6·3 ,,	0	0
,, ,, 5 ..	10·3 ,,	0	0
,, ,, 6 ..	0·8 ,,	Streptococcus	0
Lower ,, 1 ..	In fissure	Streptococcus, *B. proteus*	0
,, ,, 2 ..	,, ,,	Streptococcus, *B. proteus*	0
,, ,, 3 ..	1·5 cm.	Streptococcus	0
,, ,, 4 ..	3·5 ,,	,,	0
,, ,, 5 ..	5·5 ,,	,,	0
,, ,, 6 ..	7·7 ,,	0	0
Femur (control) ..	..	0	0
Blood from vein, Feb. 20	..	0	—

Exposure of bone to sepsis.—31 days.
Amputation.—March 8, 2.30 p.m.
Bone in ice.—From 2.30 p.m. to 3.35 p.m., March 8.
First culture taken from bone.—3.50 p.m. Last culture.—5.0 p.m.
Order of cultures.—Lower fragment : 6, 5, 4, 3, 2, 1. Upper fragment : 6, 5, 4, 3, 2, 1. Femur.

Case 14.—Sec. Lieut. B., age 28. [*Ref. No.* 207.]

Lesion.—Multiple high-explosive shell wounds. Abdomen: Penetrating upper end of left linea semilunaris; no evidence of visceral injury. Sterile secondary effusion into left pleura. Left forearm: Extensor tendons of wrist divided; cellulitis of hand; fracture of olecranon. Right hernia testis. Left leg: Compound fracture of tibia and first metatarsal. Many minor wounds.

Clinical History.—Wounded Feb. 5, 1917. All wounds opened up and drained same day at casualty clearing station. Transferred to base Feb. 21. Still profoundly septic. Pockets of pus opened on two occasions. Amputation of left leg above knee was followed by rapid improvement in general condition and healing of all wounds. Transferred to England March 22.

Examination of Limb, March 8.—Three wounds of tibia. Main fracture exposed in wound of anterior aspect of leg. Bone dry and dead-looking where visible. Soft parts adherent to bone right up to fractured ends. No pocketing of pus. Muscles of leg œdematous, with commencing fibrosis in neighbourhood of fracture. Anterior and posterior tibial vessels intact. Upper and lower tibial wounds are small cracks at bottom of suppurating sinuses. (*Fig.* 221 and *Table* 8.)

b. Effect of General Diminution of Blood-supply.

1. *Death.*—The gradual failure of circulation which not uncommonly allows the extremities to become cold for many hours before death, is particularly favourable to the growth of anaerobes and other saprophytes. (See *Case* 4 (*Fig.* 247), Appendix I, of amputation followed by death, with anaerobic penetration of 24 cm.; and contrast it with *Case* 7 (*Fig.* 212), of surviving amputation, with anaerobes confined to surface.)

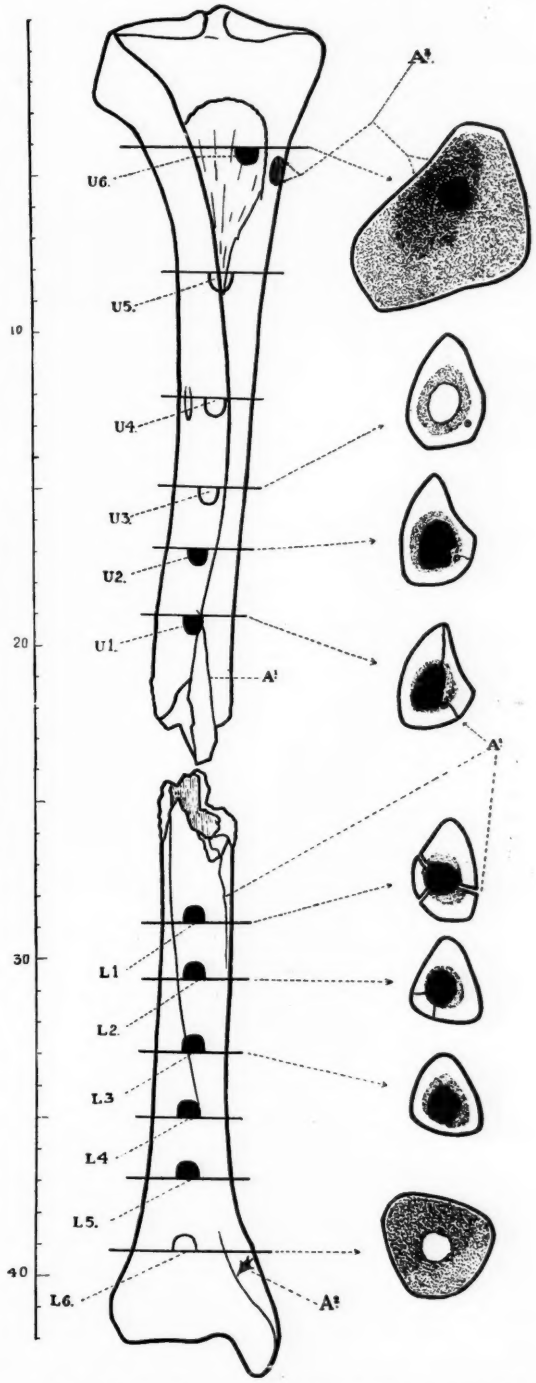


Fig. 221.—*Case* 14. Fractured tibia removed by amputation 31 days after injury. Penetration greater in lower than in upper fragment, owing to difference of blood-supply. A^1, Fissures. A^2, Small fracture with no penetration at L^6. A^3, Small fracture with penetration at U^6. Foramen for medullary artery near U^4. U, Upper fragment. L, Lower fragment.

2. *Hæmorrhage.*—After severe hæmorrhage the resistance of bone to penetration is reduced in association with the general diminution of the circulation.

i. *Hæmorrhage following Operation.*

Case 17.—Lieut. L., age 28. [*Ref. No.* 208.]

Lesion.—Superficial gutter of articular border of internal tuberosity of tibia, with tear of semilunar cartilage. Tangential blow by fragment of high-explosive shell, which remained extracapsular.

Clinical History.—Wounded July 3, 1916, 1 a.m. On July 6 arrived at base, 3 days 7 hours after being wounded. Joint effusion, consisting of blood-stained synovia, contained staphylococcus.

First operation, July 6, 6.30 p.m. (3 days 17½ hours after wound).—Local excision of track, shell-fragment, fracture, and portion of semilunar cartilage. Joint closed after irrigation.

Second operation, July 12, 9.30 p.m. (9 days 20 hours after wound).—Resection of knee-joint, including the whole of tibial fracture. Joint effusion consisting of pus —staphylococcus.

July 13, cavity packed with gauze on account of persistent oozing of blood. July 16, pyocyaneus infection of cavity.

Third operation, July 18 (6 days after resection).—Amputation through resection wound.

Aug. 15, transferred to England. April, 1917, garrison duty abroad.

Examination of Limb after Removal, July 18.—Œdema of subcutaneous tissue. Muscles macroscopically normal. No pus outside resection cavity (*Figs.* 222, 223, and *Table* 9).

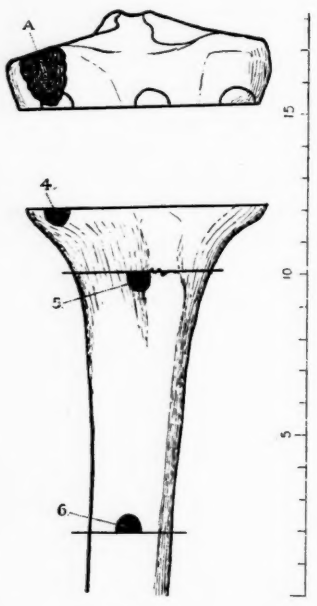


FIG. 222.

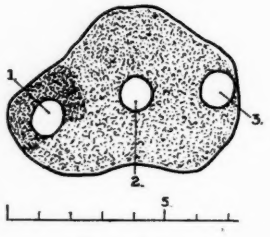


FIG. 223

FIG. 222.—*Case* 17. Tibia showing portions removed by resection and amputation. A, Original surface-wound from which no penetration occurred in ten days. After severe hæmorrhage which followed resection organisms penetrated to at least 10 cm.

FIG. 223.—*Case* 17. Tracing from lower surface of resected portion of tibia shown in *Fig.* 222. No penetration in 10 days.

This case illustrates the different degrees of penetration by organisms before and after a severe hæmorrhage. In the resected portion of the bone there was a fracture infected presumably by the staphylococcus, since that organism was present in the joint. After a period of nearly 4 days, during which penetration was possible, the surface of this fracture was removed entire by the gouge to a depth of 2 to 3 mm. After a further period of 6 days, during which the clinical appearance of a mild infection was present in the

wound, examination of the resected portion of bone showed that penetration of organisms had not reached a depth of 0·6 cm. (i.e., penetration was less than 1 cm. in 9 days). After the hæmorrhage there was penetration to at least 10 cm. in 6 days. It must, however, be pointed out that we have no knowledge of the penetrating power of *B. pyocyaneus*.

Table 9.—*Case* 17.

Specimen taken for Culture	Distance from Lesion	Aerobic Bacteria	Anaerobic Bacteria
Tibia resection 1	0·6 cm.	0	0
,, ,, 2	2·8 ,,	0	0
,, ,, 3	5·4 ,,	0	0
,, amputation 4	Surface	Staphylococcus, *B. pyocyaneus*	0
,, ,, 5	2·0 cm.	Staphylococcus, *B. pyocyaneus*	0
,, ,, 6	9·5 ,,	*B. pyocyaneus*	0
Blood from vein, July 24 ..	..	0	—
Knee-joint, July 6 and July 12	..	Staphylococcus	0

Exposure of tibia to sepsis between date of wound and date of resection of knee.—9 days.
Exposure of tibia to sepsis between resection and amputation.—6 days.
Resection.—10.30 p.m.
Bone in ice.—From 10.35 p.m. to 12.15 a.m.
First culture taken from bone.—12.25 a.m.
Last culture taken from bone.—12.35 a.m.
Order of cultures.—3, 2, 1.
Amputation.—5.45 p.m.
Bone in ice.—From 6.40 p.m. to 11.25 p.m.
First culture taken from bone.—11.30 p.m.
Last culture taken from bone.—12 midnight.
Order of cultures.—6, 5, 4.

ii. *Secondary Hæmorrhage.*

Case 15, examined twenty-four hours after severe *secondary hæmorrhage*, is described in Appendix I. Owing to division of the medullary artery, it is not possible to estimate the effect of the secondary hæmorrhage in the production of the extensive penetration observed.

6. **Influence of Surgical Treatment of Wounds on Penetration.**—The results obtained from the study of the material which forms the basis of this communication do not represent the natural history of untreated gunshot fracture. In the majority of cases it must be assumed that this has been modified by the ordinary surgical technique of cleansing and drainage of wounds.*

* By surgical cleansing is meant the removal of all dead tissue and foreign matter (mud, cloth, and missile) from a wound. By drainage is meant the establishment of free communication of all parts of the wound with the surface. The aim of these procedures is to prevent the saprophytic growth of bacteria in wounds which precedes parasitic invasion of the living tissues.

In none of the cases was any attempt made to bring about surgical sterilization of the wound by the continuous or intermittent instillation of antiseptics. The ordinary routine was as follows :—

Soft Parts : The wound was excised or opened freely so as to allow of either gravity drainage by tubes, or gauze drainage of a funnel-shaped wound.

Bone : All comminuted cancellous tissue lying on the surface of the bone wound was removed by gouge or curette, on the assumption that such bone was killed by the direct effect of the missile, and consequently formed a suitable nidus for bacteria. The firm bruised portion was not removed. The treatment as a whole constitutes in effect the establishment of drainage for the bone.

a. Penetration in Fracture with Untreated Bone.

The following represent (i) Early, and (ii) Late stages in the evolution of an untreated septic fracture :—

i. *Early Stage.*—This is shown in *Case* 18, Appendix I.

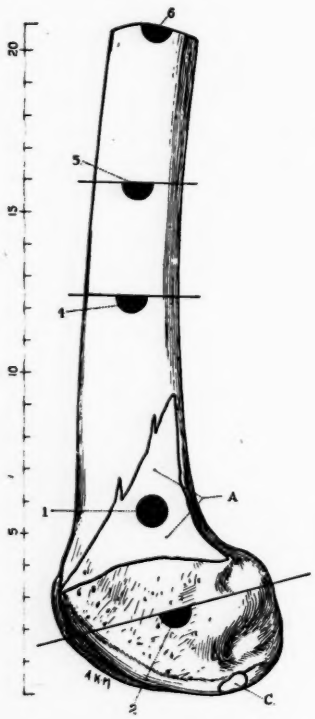


Fig. 224.

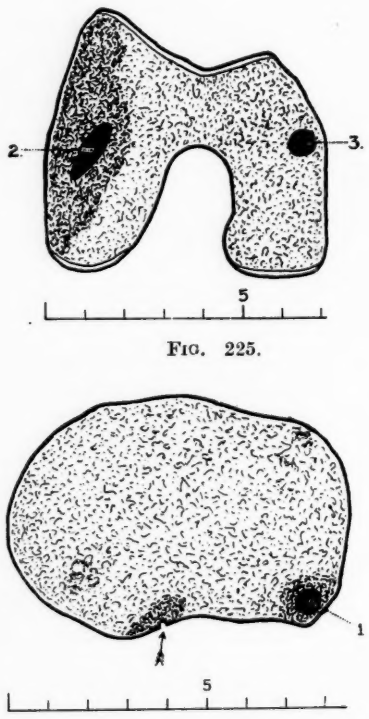


Fig. 225.

Fig. 226.

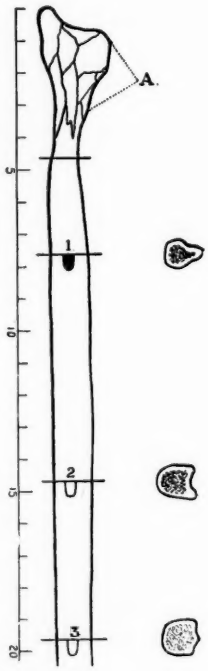


Fig. 227.

Fig. 224.—*Case* 19. Femur removed by amputation. No surgical interference with actual fracture. Growth throughout bone. A, Fracture.

Fig. 225.—*Case* 19. Transverse section of femur shown in *Fig.* 224 at level of (2). Growth throughout bruised and uninjured bone.

Fig. 226.—*Case* 19. Transverse section of upper end of tibia, showing penetration from small untreated fracture (indicated by arrow). Specimen 1 taken from indirect bruise beneath superior fibular facet. Specimen 2 in *Table* 10 was from opposite tuberosity 2 cm. lower.

Fig. 227.—*Case* 19. Fibula showing fracture of head, and associated penetration.

ii. *Late Stage.*—In the following case, and in *Case* 20, Appendix I, the interval which elapsed between wound and amputation is not known with certainty. From the data available it was between 7 and 14 days. In both cases the flesh wound had been partially opened up, but the bone had clearly not been interfered with in any way.

Case 19.—Pte. P.

Clinical History.—Amputation in lower third of thigh for suppurative arthritis of knee. Early tetanus with local spasm.

Examination of Limb after Removal.—Vertical gutter wound on outer side of knee, extending from upper border of patella to level of tibial tubercle. In the upper third of this was the mouth of a sinus leading down to a gutter fracture of the external condyle of the femur (*Fig.* 224). In the lower third was the mouth of a similar sinus leading to a small wound of the external tuberosity of the tibia. Behind this sinus the comminuted head of the fibula lay bare in the wound. Pus tracks from femur, 4 cm. upwards, deep to vastus externus; from tibia, one-third down leg, in anterior tibial compartment; from fibula, 5 cm. downwards, in subcutaneous tissue.

Knee-joint: no tension, free exit of pus through sinuses; articular cartilage—white, intact; synovial membrane—superficial sloughing; effusion—yellow pus; extracapsular extension of pus—nil; popliteal space—intact; no foreign body. (*Figs.* 224, 225, 226, 227.)

Table 10.—*Case* 19.

Specimen taken for culture	Distance from lesion	Aerobic Bacteria	Anaerobic Bacteria
Femur 1	Surface	Streptococcus, coliform bacillus, Gram+ diplococcus	+ (including *B. perfringens* and tetanus-like bacillus)
,, 2	1·4 cm.	Streptococcus, coliform bacillus, minute Gram+ diplococcus, minute Gram+ staphyloccocus	+
,, 3	4·7 ,,	Streptococcus, coliform bacillus, minute Gram+ diplococcus, minute Gram+ staphylococcus	+ (including tetanus-like bacillus)
,, 4	2·8 ,,	Coliform bacillus, minute Gram+ staphylococcus	+
,, 5	6·1 ,,	Coliform bacillus	0
,, 6	11·0 ,,	Coliform bacillus	0
Tibia 1	3·3 ,,	Coliform bacillus, Gram+ diplococcus, Gram+ slender bacillus in chains	+
,, 2	3·5 ,, (about)	Coliform bacillus, Gram+ diplococcus, Gram+ slender bacillus in chains	+ (including *B. perfringens*)
Fibula 1	3·6 cm.	Coliform bacillus	0
,, 2	10·2 ,,	0	0
,, 3	15·6 ,,	0	0
Knee-joint	..	Streptococcus, coliform bacillus	+ (including *B. perfringens*)

Amputation.—June 23, 1916, 11.40 a.m.
Limb in ice.—From 12 noon to 3.30 p.m., June 23.
First culture taken from bone.—4.0 p.m.
Last culture taken from bone.—7.0 p.m.
Order of cultures.—Femur: 6, 5, 4, 1, 3, 2. Tibia: 1, 2. Fibula: 1, 2, 3.

This case, and *Case* 20, Appendix I, suggest that the presence of the dead comminuted surface-layer of cancellous bone facilitates the growth of a mixture of organisms, and that, in consequence of the unchecked proliferation on such a surface, extensive penetration occurs.

b. Penetration with Obstruction of Drainage.

As a general principle it may be stated that, in a septic flesh wound infiltration of the walls by organisms is in inverse proportion to freedom of drainage.

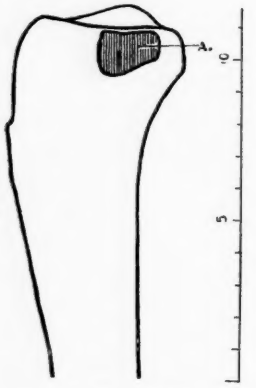


Fig. 228.

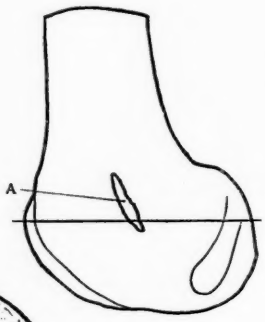
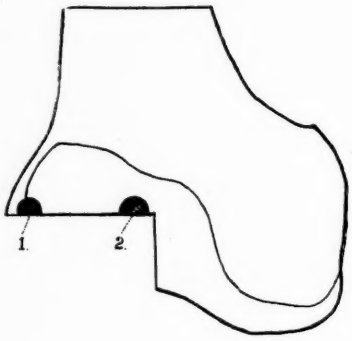


Fig. 230.



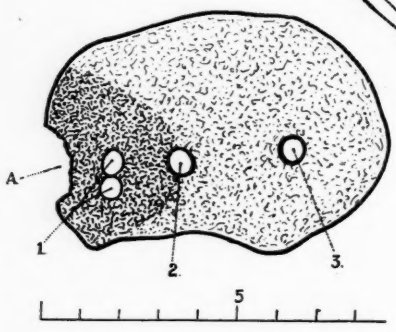


Fig. 229.

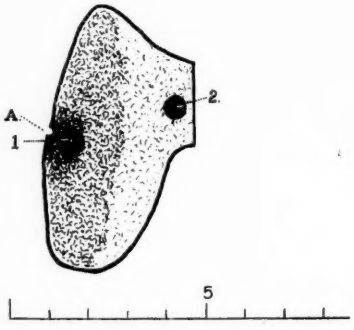


Fig. 231.

Fig. 228.—*Case* 21. Size and position of tibial wound (surface gutter).

Fig. 229.—*Case* 21. Tracing of transverse section through tibial wound shown in *Fig.* 228. Removed by amputation 16 days after injury. No penetration with free drainage. A, Wound.

Fig. 230.—*Case* 21. Size and position of femoral wound. Obstruction of drainage by knee-joint between fracture and surface.

Fig. 231.—*Case* 21. Tracing of section of femoral condyle through wound shown in *Fig.* 230. Penetration to at least 2·8 cm. from wound with obstructed drainage. Limit not reached.

In bone wounds, apart from untreated fractures, it is difficult to obtain examples of obstruction of drainage, for the reason that only some unusual combination of circumstances can afford the opportunity.

The following have been met with in our experience :—

i. *Influence on Penetration of Inadequate Drainage of Soft Parts.*

Infected amputation stump closed by suture of the flaps (*Case* 4, Appendix I). The primary effect of closure of the stump on penetration was overshadowed by the terminal stages of the disease.

Interruption of the drainage track by an infected joint through which a continuous feed of streptococcus led to increase of penetration (*Case* 21). This case affords a comparison between two similar wounds with different degrees of drainage in the same patient. The tibial wound was close to the surface, well open, and had had the superficial damaged bone removed by curetting. The femoral wound communicated with the surface by a narrow track, across the course of which lay the infected knee-joint. The drainage of this wound was not only obstructed, but a continuous reinforcement of its surface infection took place from the neighbouring joint. The foreign body and superficial layer of damaged bone had not been removed.

Case 21.—Major G., age 36. [*Ref. No.* 211.]

Lesion.—Small surface gutter of tibia, not communicating with knee-joint. Small perforating wound of knee-joint, with crack of external condyle of femur near attachment of lateral ligament. Shell fragments in both bones. Numerous other wounds from fragments of high-explosive shell.

Clinical History.—Wounded June 2, 1916. No operation before arrival at base on June 4, when all wounds except that into knee-joint were opened up, cleaned, and foreign bodies removed. Aspiration of knee-joint on account of increased effusion: turbid yellow fluid—streptococcus—June 12. Tibial wound excised and bone curetted. Track to knee-joint excised. HClO irrigation. Synovial membrane closed. Wound packed June 14. Amputation above knee June 18, 2.30 p.m. Transferred to England July 4. (*Figs.* 228, 229—Drainage good. *Figs.* 230, 231—Drainage obstructed.)

Table 11.—*Case* 21.

Specimen taken for Culture	Distance from Lesion	Afrobic Bacteria	Anaerobic Bacteria
Tibia 1	0·7 cm.	0	0
„ 2	2·4 „	0	0
„ 3	5·2 „	0	0
Femur 1	0·2 „	Streptococcus	0
„ 2	2·8 „	„	0
Knee-joint, June 12 ..	..	„	0
„ June 13 ..	..	„	0
„ June 16 ..	..	„	0
Blood from vein at amputation	..	0	0

Exposure of bones to sepsis.—16 days.
Dissection of limb commenced.—3.0 p.m., June 18.
Last culture taken from bone.—5.20 p.m.
Order of cultures.—Tibia: 3, 2, 1. Femur: 2, 1.

ii. *Influence on Penetration of Inadequate Drainage of Bone* (*Case* 22).

In this case three bones opened into a single septic cavity, but while the drainage of the radius and ulna was as complete as possible, that of the humerus was limited to a small opening in the articular surface.

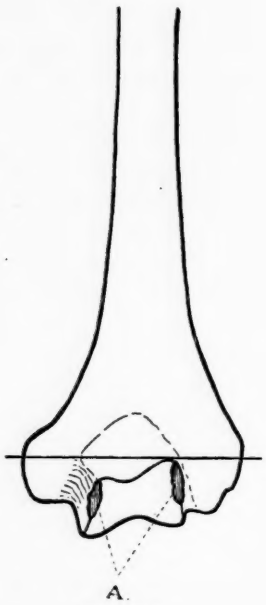


FIG. 232.

FIG. 232.—*Case* 22. Lower part of humerus removed by amputation 18 days after injury, showing small fractures. Purulent cancellous osteitis at level of section due to obstructed drainage of bone. Pure staphylococcus infection.

FIG. 233.—*Case* 22. Forearm bones removed by amputation: radius 16 days after resection of uninjured head; ulna 18 days after gunshot fracture. Penetration limited to 4 cm.; absence of macroscopic osteitis associated with free drainage of bones.

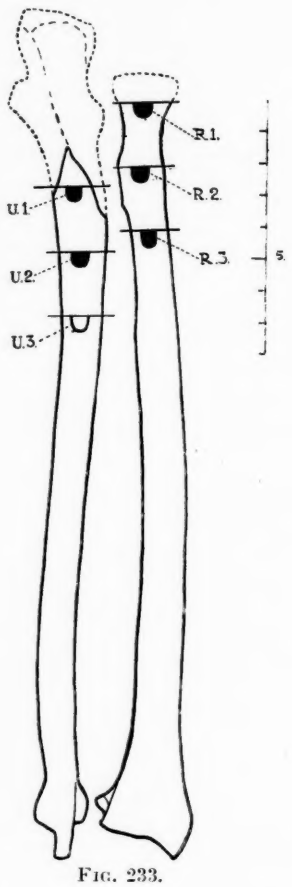


FIG. 233.

Table 12.—*Case* 22.

SPECIMEN TAKEN FOR CULTURE	DISTANCE FROM LESION	AEROBIC BACTERIA	ANAEROBIC BACTERIA
Humerus	At level of section of condyles	Staphylococcus	0
Radius 1	Surface	,,	0
,, 2	2·0 cm.	,,	0
,, 3	4·0 ,,	,,	0
Ulna 1	Surface	..	0
,, 2	1·2 ,,	..	0
,, 3	3·2 ,,	0	0
Elbow-joint, May 30	..	Staphylococcus, *B. coli*	0
,, May 31	..	,, ,,	0

Exposure of bones to sepsis.—Radius, 16 days; humerus and ulna, 18 days.
Amputation.—5.15 p.m. Humerus culture taken.—5.15 p.m.
First culture taken from radius.—6.30 p.m. Last culture taken from ulna.—7.5 p.m.
Order of cultures.—Humerus. Radius: 1, 2, 3. Ulna: 1, 2, 3.

Direct smear from sawn humerus showed pus cells and staphylococci.
The original tube of Radius 3 containing the bone-fragment grew, whilst a sample sub-cultured at once from this did not, showing that few organisms were present, and suggesting that this section was near the limit of penetration.

Case 22.—Lieut. G., age 22. [*Ref. No.* 212.]

Lesion.—High-explosive shell wound over olecranon process. Comminution of upper extremity of ulna. Chip from edge of trochlea of humerus. Radius uninjured.

Clinical History.—Wounded May 13, 1916, at night.

Operation, May 15.—Resection of comminuted portion of ulna and head of radius. Chipped edges of trochlea curetted. Exposed cancellous bone of humerus bruised. Drainage and irrigation of wound. Second operation, May 31.—Purulent cancellous osteomyelitis of humerus. Pus extended to upper limit of cancellous bone. Lower part of medulla looks infected, but is not purulent. Healthy bleeding marrow reached at middle of shaft. Amputation at this level, 5.15 p.m. Transferred to England June 12. Sequestrectomy, July 27, Sept. 17, and Jan. 6, 1917. Discharged from hospital Jan. 22, with healed wound and useful stump.

Clinical Picture.—Osteomyelitis.

Examination of Limb, May 31, 1916. No pus apart from humerus. Œdema of arm, but not of forearm. (*Figs.* 232, 233, and *Table* 12.)

c. Penetration in Presence of Undrained Fissure.

Case 23.—Lieut. C., age 40. [*Ref. No.* 213.]

Lesion.—Fracture of external condyle of humerus, with crack into elbow-joint. Other minor flesh-wounds from high-explosive shell.

Clinical History.—Wounded Dec. 12, 1916. Shell fragments removed at base Dec. 16. Local operation on elbow wound, drainage improved and fracture curetted, elbow-joint not infected Jan. 1, 1917. Resection for arthritis of elbow Jan. 14. Transferred to England Feb. 14.

Although interference with the local blood-supply in the neighbourhood of the external condyle may have facilitated penetration, the chief factor was probably the feed of organisms from the imperfectly drained fissures shown in the diagram (*Fig.* 234).

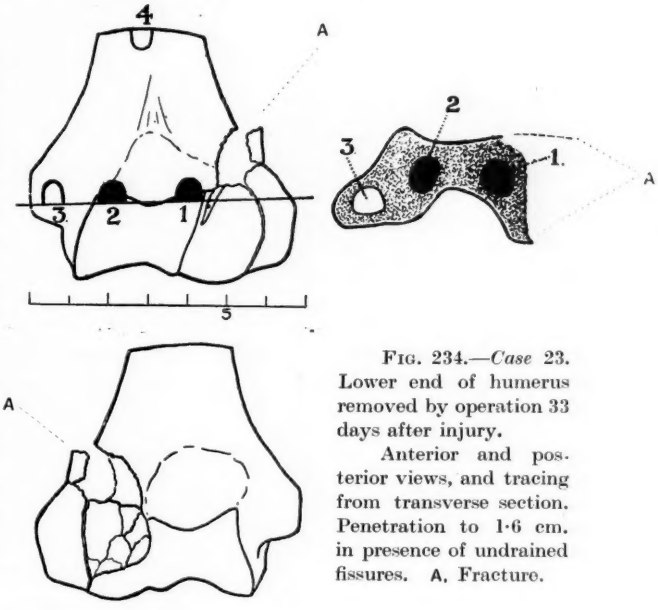


Fig. 234.—*Case* 23. Lower end of humerus removed by operation 33 days after injury.

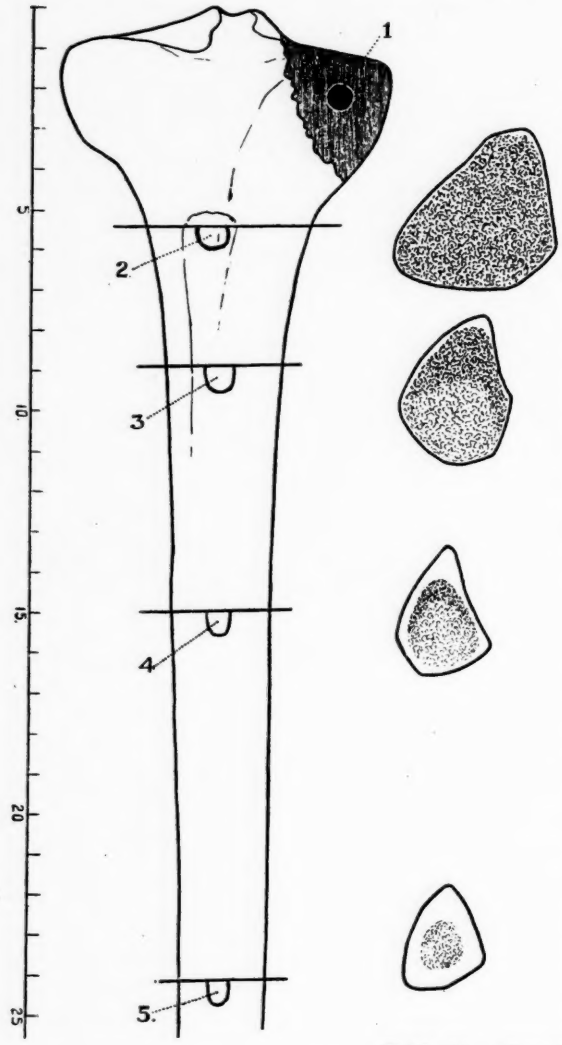
Anterior and posterior views, and tracing from transverse section. Penetration to 1·6 cm. in presence of undrained fissures. A, Fracture.

Table 13.—*Case* 23.

Specimen taken for culture	Distance from lesion	Aerobic bacteria	Anaerobic bacteria
Humerus 1	0·3 cm.	Streptococcus	0
„ 2	1·6 „	„	0
„ 3	3·3 „	0	0
„ 4	3·0 „	0	0
Ulna (control)	..	0	0
Blood from vein at amputation	..	0	0

Exposure of bone to sepsis.—33 days. Resection.—3.30 p.m., Jan. 14, 1917.
Bone in ice.—From 3.30 p.m. to 5.30 p.m., Jan. 14.
First culture taken from bone.—5.45 p.m. Last culture.—6.20 p.m.
Order of cultures.—Humerus: 4, 3, 2, 1. Ulna.

d. Penetration in Well-drained Bone with Extensive Reinforcement of Sepsis from the Soft Parts.



Case 24.—Pte. H. [*Ref. No.* 214.]

Clinical History.—Wounded May 13, 1916. Amputation May 17, 5.30 p.m.

Lesion.—Large foul wound of inner side of knee, opening joint. Comminution of internal condyle of tibia and femur.

Examination of Limb, May 17, 7.30 p.m.—Wound extended from inner border of patella to inner hamstrings. Joint widely open and contained a little brownish pus. Cartilage not eroded. No extracapsular extension of pus apart from wound, and no œdema of leg. Large foul pus-cavity extended up to level of amputation between vastus externus and femur; this was an extension from the original wound. (*Fig.* 235 and *Table* 14.)

With this last case may be compared the original tibial wound of *Case* 7. In both instances pus from the knee-joint flowed over the fracture on its way to the surface, and in

Fig. 235.—*Case* 24. Tibia removed by amputation 4 days after injury. Shell wound of internal tuberosity. Bruise extends to Section 4 (11·4 cm. from fracture). Penetration less than 3 cm. in well-drained bone with reinforcement of sepsis from soft parts.

Table 14.—*Case* 24.

Specimen taken for Culture	Distance from Lesion	Aerobic Bacteria	Anaerobic Bacteria
Tibia 1	Surface	Streptococcus, coliform bacilli	+
,, 2	2·9 cm.	0	0
,, 3	5·5 ,,	0	0
,, 4	11·4 ,,	0	0
,, 5	21·0 ,,	0	0
Knee-joint pus ..	..	Streptococcus, coliform bacilli, Gram − cocci	+ (including *B. perfringens*)

Exposure of bone to sepsis.—4 days.

Case 24 there was a further addition of sepsis from a large cavity in muscle. In spite of this, the freedom of drainage of the bone was adequate to prevent extensive penetration.

e. Absence of Penetration with Free Drainage of Bone and Soft Parts.

An example of this is given in the tibial wound of *Case* 21.

The series of cases described above shows that the degree of penetration is inversely proportional to the adequacy of drainage established by surgical interference. An estimate of the depth to which uncomminuted, bruised, cancellous bone requires removal by operation should be based upon a consideration of the factors which have been shown to influence penetration, especially the extent and intensity of infection of the soft parts and the length of time during which the wound has remained untreated since infliction. Bruising, *per se*, is not an indication for removal of bone.

7. **Influence of Time on Penetration.**—In estimating the relationship between the length of time during which a bone is exposed to infection and the degree of penetration by organisms, cases in which growth is clearly enhanced by diminution of blood-supply or by obstruction of drainage must be excluded.

In *Table* 15 are grouped 16 observations on bones in which no complications are introduced by these factors.

Table 15.—Showing the Relation between Time and Penetration.

Case	Bone	Time	Penetration	Sterile at	Organisms at Limit
12	Calcaneum ..	2·5 days	0·5 cm.	1·8 cm.	Anaerobes
12	Tibia	2·5 ,,	1·0 ,,	4·2 ,,	Staphylococcus, anaerobes
26	Humerus ..	3 ,,	Surface	0·5 ,,	Staphylococcus, anaerobes
18	Femur	3·5 ,,	0·8 cm.	1·9 ,,	Anaerobes
24	Tibia	4 ,,	Surface	2·9 ,,	Streptococcus, coliform bacilli
7	Tibia	10 ,,	2·0 cm.	2·5 ,,	Streptococcus
7	Tibia (amputatn.)	10 ,,	Surface	1·5 ,,	Mixed
7	Fibula ,,	10 ,,	Surface	2·0 ,,	Staphylococcus
9	Tibia	14 ,,	0·8 cm.	4·7 ,,	*B. coli*, anaerobes
6	,, (amputation)	16 ,,	1·5 ,,	4·0 ,,	Streptococcus, staphylococcus
21	,, ...	16 ,,	Surface	0·7 ,,	Streptococcus
8	,, ...	23 ,,	2·0 cm.	11·2 ,, (no section made between 2 and 11 cm.)	,,
23	Humerus ..	23 ,,	1·6 ,,	3·3 cm.	,,
25	Femur	26 ,,	Surface	1·5 ,,	,,
14	Tibia, upper fragment ..	31 ,,	1·5 cm.	3·5 ,,	,,
14	,, head ..	31 ,,	0·8 ,,	3·0 ,,	,,

Although the number is too small to allow of detailed analysis, a general consideration of the table brings out two points: Firstly, cases in which organisms are confined to the surface are equally spaced over the first four weeks. The continued presence of organisms in contact with open bone does not, therefore, necessarily lead to infection of the deeper layers. Secondly, if the average depth of penetration reached in the first week be compared with the average depth reached during the succeeding four weeks, the process does not appear to be one of uncontrolled progression. Thus, the average penetration by organisms in the first week is 0·46 cm. (five observations),

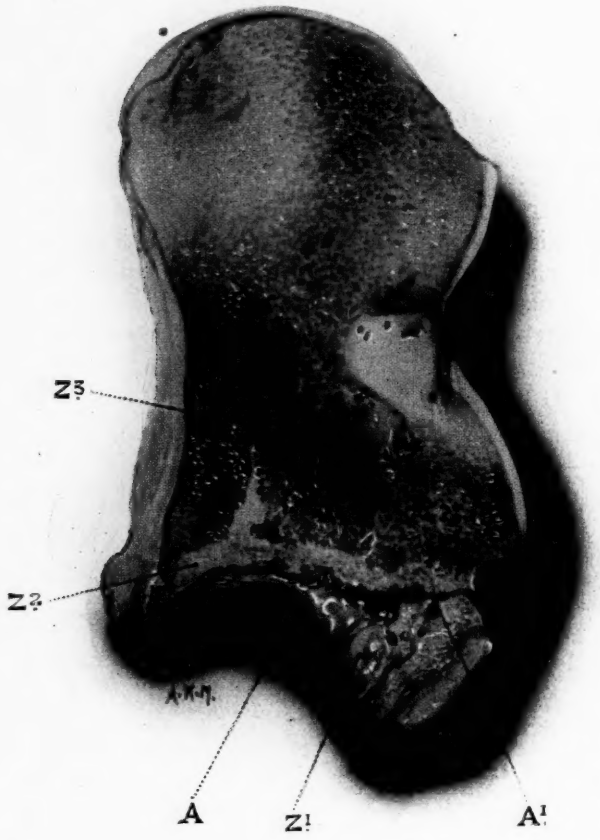


FIG. 236.

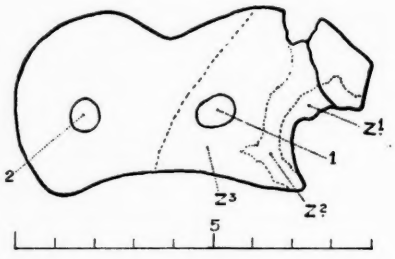


FIG. 237

FIG. 236.—*Case* 25. Upper surface of lower extremity of femur resected 26 days after injury.

A, Original shell-wound curetted 2 days after infliction. A^1, Fissure through which streptococcus reached knee-joint. Z^1, Granulation tissue resting on a thin layer of bone which contained pus cells and streptococcus. Z^2, Fibrous tissue filling cancellous spaces; deep to this the bone was softer than normal. Z^3, Bone of normal consistence; red colour probably due to inflammatory hyperæmia, but may be partly residual from original bruise. Beyond this, normal bone. (*See key figure—Fig.* 237.)

FIG. 237.—*Case* 25. Tracing from bone shown in *Fig.* 236. Z^1, Granulation tissue lining original wound. Z^2, Zone of sclerosed bone. Z^3, Zone of hyperæmia. 1, Junction of hard and softened bone. 2, Normal hard bone.

while the average additional penetration during the succeeding four weeks is 0·46 cm. (eleven observations). These figures suggest that, where penetration beneath the surface occurs, the rate is greater during the first few days than during the succeeding weeks.

Although there is no evidence as to the mechanism by which the slowing of the rate of penetration is brought about, it is natural to suppose that it is in the nature of an immunity reaction. At a later date the development of a defensive reaction associated with the process of repair is suggested by the conditions found in *Case* 25, the only instance met with in the series.

Case 25.—Sec.-Lieut. B., age 22. [*Ref. No.* 215.]

Lesion.—High-explosive shell wound of internal condyle of femur. Fissure into knee-joint.

Clinical History.—Wounded Aug. 4, 1916. Two days afterwards the shell fragment was removed and its site curetted at a casualty clearing station. Arrived at base nine days after being wounded, with streptococcal arthritis of knee. Limb immobilized. Resection of knee-joint Aug. 30, twenty-six days after being wounded. Transferred to England. Limb still in plaster, April, 1917.

Joint at Resection.—Cartilage : eroded at points of pressure. Synovial membrane : surface replaced by soft granulation tissue. Effusion : pus. Extracapsular extension : nil. Periarticular œdema : considerable.

Examination of Bone Removed, Aug. 30 (*Figs.* 236 and 237).—The surface illustrated in *Fig.* 236, when examined with a dissecting microscope, showed that the grey zone deep to the layer of granulations consisted of two areas : (1) A narrow superficial strip showing definite osteomyelitis, especially near the fissure—i.e., the cancellous spaces were filled with pus ; (2) Deep to this a dense white zone, the cancellous spaces of which looked solid in contrast with the empty cancellous spaces of the adjacent red area. Considerable numbers of streptococci were found in the pus of the superficial area, and although it was difficult to obtain a good smear, none were seen in the sclerosed area. The red cancellous bone deep to the sclerosed zone was softened as far as Specimen 1, which was taken at the junction of hard and soft bone.

Table 16.—*Case* 25.

Specimen taken for Culture	Distance from Lesion	Aerobic Bacteria	Anaerobic Bacteria
Femur 1 (soft bone) ..	1·5 cm.	0	0
„ 2 (hard „ ..	4·0 „	0	0
Knee-joint, Aug. 13 ..	..	Streptococcus	0
„ Aug. 21 ..	..	„	0

Exposure of bone to sepsis.—26 days.
Resection.—3.30 p.m.
Bone in ice.—From 3.30 p.m. to 6.30 p.m.
First culture taken from bone.—6.40 p.m.
Last culture taken from bone.—6.45 p.m.
Order of cultures.—2, 1.

IV. EXTENSION OF INFECTION ALONG OPEN FISSURES.

A fissure whose walls are not in contact affords ample opportunity for the growth of any organisms which may be present in the wound, as it provides a cavity with rigid walls, full of blood-clot, and defiant of drainage. Its behaviour can be studied clinically in an infected fracture of the femur, accompanied by fissuring, where the incisions for drainage have been confined to the region of complete solution of continuity. The fissure, full of blod-clot, is then in communication at one end with the wound flora, and at the other end opens either into a muscle or joint-cavity.

Organisms grow along the fissure from the point of primary infection, and since lateral penetration of the bone by organisms, and toxic absorption from the walls of the fissure, are comparatively slight, the process of extension is not reflected to a noticeable degree in the temperature chart, pulse-rate, or general

condition of the patient. As soon, however, as bacteria escape from the fissure into an adjacent muscle or joint-cavity, the clinical picture changes to that associated with pocketing or with the development of a septic arthritis.

The absolute rate of travel of organisms along a fissure can only be determined by the bacteriological examination of serial sections of bones removed by operation. Estimates of the apparent rate of travel have been founded, from a clinical point of view, on the appearance of infection in a joint at the far end of a fissure. This use of a joint as an indicator is probably fallacious, since it implies the assumption that no delay occurs at the breach in the synovial surface. Delay is known to occur in the case of anaerobes and the staphylococcus (see *Case* 27), and probably happens in a less degree in the case of the streptococcus, although the material available does not allow of precise statement with regard to this organism.

The two methods are illustrated in *Cases* 26 and 27. *Case* 27 also illustrates the persistence of anaerobes in a fissure after they have disappeared from the original wound.

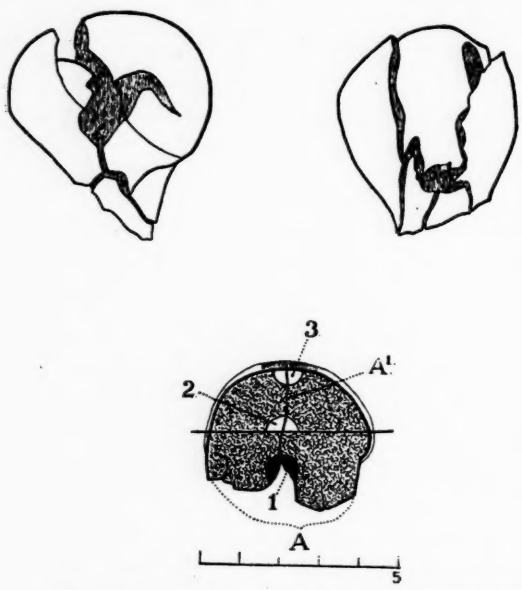


FIG. 238.—*Case* 26. Head of humerus removed by operation 3 days after injury. Anterior and external views and section. A, Main fracture of surgical neck. A^1, Fissure, showing no extension of organisms. Whole head bruised.

Examination of a Fissure at an Early Stage before Extension has taken place.

Case 26.—Sec.-Lieut. B., age 35. [*Ref.* 216.]

Lesion.—Neck of humerus shattered by rifle bullet. Gas infection of soft parts.

Clinical History.—Wounded Sept. 14, 1916. Limited excision of surface wound, with tube drainage, at casualty clearing station. Rapid swelling of shoulder. *X* rays showed that the fissure extended to the shoulder-joint. Sepsis rapidly subsided after resection on Sept. 17, 4.15 p.m. Transferred to England Oct. 1. (*Fig.* 238).

Table 17.—*Case* 26.

SPECIMEN TAKEN FOR CULTURE	DISTANCE FROM LESION	AEROBIC BACTERIA	ANAEROBIC BACTERIA
Humerus 1 ..	Surface	Staphylococcus	+
,, 2 ..	0·5 cm.	0	0
,, 3 ..	1·8 ,,	0	0

Exposure of bone to sepsis.—3 days.
Bone in ice.—From 4.20 p.m. to 6.10 p.m., Sept. 17.
First culture taken from bone.—6.20 p.m.
Last culture taken from bone.—6.45 p.m.
Order of cultures.—3, 1, 2.

Examination of Fissure at a Later Stage after Extension of Infection into Joint.

Case 27.—Lieut. H., age 21. [*Ref. No.* 217.]

Lesion.—Comminuted shell fracture of femur 9 cm. from lower end. Fissure into knee-joint.

Clinical History.—Wounded Aug. 18, 1916. Incisions for drainage and removal of shell fragment at casualty clearing station, Aug. 19. Further incisions for drainage at base, Aug. 21. Much laceration of thigh muscles, with severe infection. Bubbles of gas in pus from wound. The knee-joint at first had the usual quiet effusion associated with fracture of the lower third of the femur.

The first complaint of pain in the knee was on the evening of Sept. 3. The following morning it was tender and hot, with increased effusion. Aspiration yielded a turbid fluid containing the streptococcus. Amputation, Sept. 4. Transferred to England, Sept. 17.

Examination of Limb, Sept. 4.—Femur: Periosteum thickened above and around fracture. Continuity of pus along main fissure from fracture to joint. Muscles: Abscess in crureus at level of amputation, communicating with fracture. Knee-joint: Early arthritis. Synovial membrane injected. Articular cartilage unaltered. (*Figs.* 239, 240, 241, 242.)

Table 18.—*Case* 27.

Specimen taken for Culture	Distance from Lesion	Aerobic Bacteria	Anaerobic Bacteria
Femur 1 (soft bone)	In fissure	Streptococcus, staphylococcus, *B. coli*	+ (including *B. perfringens*)
„ 2	0·4 cm.	Streptococcus, staphylococcus, *B. coli*	0
„ 3	1·5 „	0	0
„ 4	4·1 „	0	0
Pus from wound at amputation	..	Streptococcus, staphylococcus, *B. coli*	0
Blood from vein at amputation	..	0	—

Exposure of bone to sepsis.—17 days.
Amputation.—9.30 p.m.
Bone in ice.—From 9.30 p.m. to 10.55 p.m.
First culture taken from bone.—11.30 p.m.
Last culture taken from bone.—12 midnight.
Order of cultures.—4, 3, 2, 1.

Table 19.—*Case* 27. Knee-joint.

Days after infliction of Wound	Effusion	Organism
7	Blood-stained, synovial	0
9	„ „	0
17	Turbid yellow; very few pus cells; the turbidity due almost entirely to organisms	Streptococcus

Table 20.—*Case* 27. Examination of Direct Smears.

Point from which taken	Cells	Organism
Femur 1, in crack at level of section of condyles	Pus	Streptococcus
Marrow, 2·5 cm. above fracture	Excess of reds	0
,, 5 ,, ,, ,,	Fewer reds	0
,, 7·5 ,, ,, ,,	Normal marrow	0

Description of Figs. 239, 240, 241, 242.

Fig. 239.—*Case* 27. Lower half of femur removed by amputation for streptococcal arthritis of knee 17 days after injury. Longitudinal section of bone, with fissure opened out to show continuity of pus from fracture to articular cartilage. A, Fracture. A^1, Fissure extending to joint. Same femur as in *Figs.* 240, 241, 242.

Fig. 240.—*Case* 27. Lower fragment of fractured femur with fissure (A^1) into knee-joint.

Fig. 241.—*Case* 27. Femur shown in *Fig.* 240 from below. A^1, Continuation of fissure through articular cartilage.

Fig. 242.—*Case* 27. Transverse section through condyles of femur shown in *Fig.* 240. A^1, Fissure in bruised condyle. Removed by amputation 17 days after injury. Penetration 0·4 cm. from fissure. Shows lateral penetration from fissure at a distance from the main fracture.

V. CONCLUSIONS.

1. From the surface of a divided or fractured bone exposed to infection, bacteria may penetrate to the deeper parts.

2. In an untreated fracture, penetration is apparently unlimited.

3. If the dead bone on the surface of the fracture is removed early, penetration is much reduced, and may not occur at all.

4. Penetration, particularly of anaerobes, is greatly increased by reduction of the circulation through the injured bone.

5. Penetration is increased by obstruction to drainage, either of the bone or of the soft parts.

6. The order of frequency and power of penetration of the bacteria found is: (1) Streptococcus; (2) Staphylococcus; (3) Anaerobes; (4) *B. coli.*

7. The rate of penetration is at its maximum during the first few days.

8. In the material examined, no difference in reaction to penetration has been noted between cancellous bone and the marrow of the shaft.

9. Bruising—an invariable accompaniment of projectile fracture—does not appear to facilitate penetration if the surface layer of débris is removed and drainage established.

10. In a septic fissure, growth of bacteria is progressive, and may lead to infection of a distant part—for example, a joint. Dissemination of infection throughout a bone takes place by penetration from its walls.

We wish to express our appreciation of the valuable help afforded us by Major J. W. West, R.A.M.C., in obtaining some of the material; of the intelligent co-operation of Private W. A. Hume (now Second Lieutenant R.F.A.), and Sergeant A. F. Collett, R.A.M.C.; and also of the skilful illustrations in line and colour by Sergeant A. K. Maxwell, R.A.M.C., for whose assistance we are indebted to the Medical Research Committee.

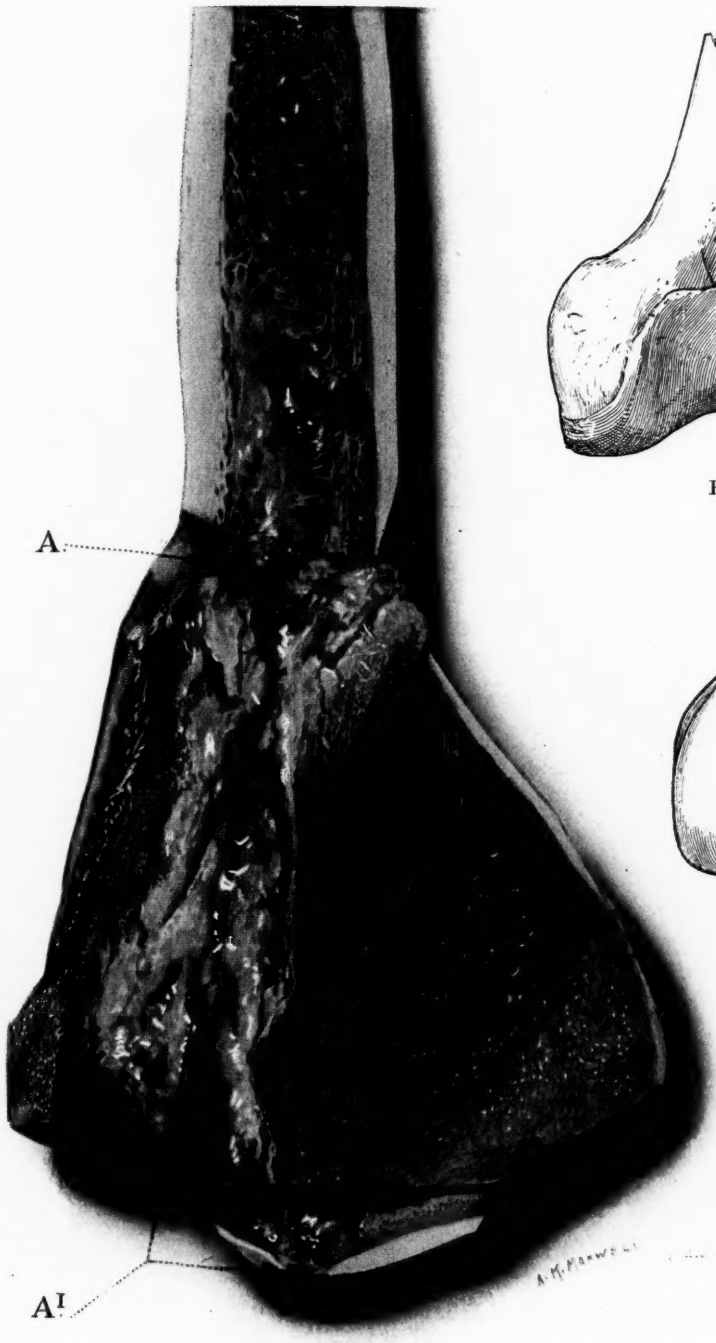


Fig. 239.

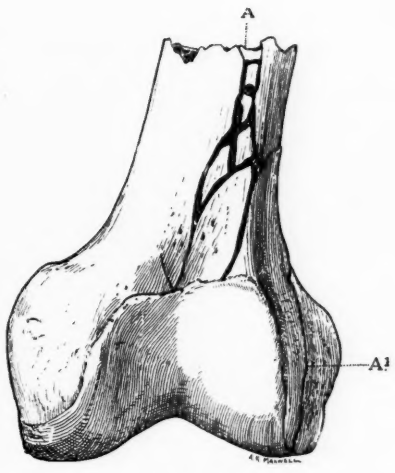


Fig. 240.

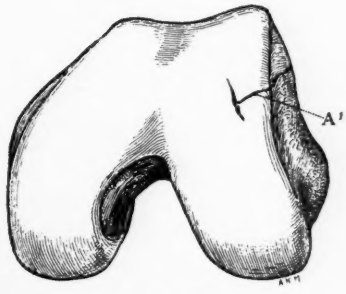


Fig. 241.

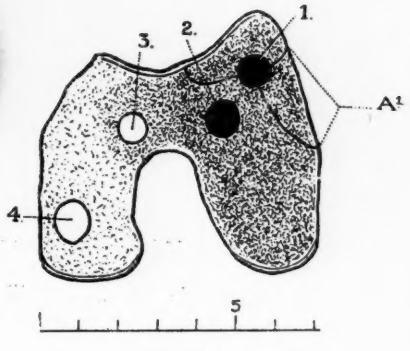


Fig. 242.

APPENDIX I.

SUMMARY OF CONTENTS.

Post-mortem growth in bone.—*Cases* 1, 2, 3.
Effect on penetration of the circulatory conditions preceding death.—*Cases* 4, 5.
Additional examples of penetration through normal bone.—*Cases* 6, 8.
Illustrations of the low penetrating power of *B. coli*.—*Cases* 9, 10.
Additional examples of extensive penetration associated with interruption of the medullary artery.—*Cases* 15, 16.
Additional examples illustrating early and late stages of penetration in untreated septic fracture.—*Cases* 18, 20.

Post-mortem Growth in Bone (*Cases* 1, 2, 3).—The importance of using fresh material is shown by the following observations. Three limbs, amputated in the lower third of the thigh for septic arthritis of the knee, were left for 21, 28, and 28½ hours respectively at room temperature in May, at the end of which time the femurs were examined for the presence of organisms. In all three the cut end of the femur was soiled by pus from the wound, and in *Cases* 2 and 3 this was the only opening by which organisms could enter the bone; in *Case* 1, owing to a fracture of the external condyle, the bone was open to infection at both ends. In *Cases* 1 and 2 growth was general throughout the bone, while in *Case* 3 the limit was fixed at about 11 cm. in 28½ hours.

Case 1.—Pte. R., age 26. Wounded April 24, 1916. Amputation 11.0 a.m. May 1. Examination of bone 2.30 p.m. May 2. Sepsis before amputation, 7 days. Duration of post-mortem growth, 28 hours.

Lesion.—Open septic knee-joint, with fracture and bruise of external condyle of femur (*Fig.* 243).

Table 21.—*Case* 1.

Specimen taken for Culture	Distance from Source of Infection	Aerobic Bacteria	Anaerobic Bacteria
Femur 1	In fissure	Streptococcus, staphylococcus	0
,, 2	1·0 cm.	Streptococcus	0
,, 3	3·7 ,,	,,	0
,, 4	4·0 ,,	,,	0
,, 5	2·0 ,,	,,	0

Conclusion.—In 28 hours, growth to at least 5 cm.; limit not reached.

Case 2.—Pte. W. Wounded April 27, 1916. Amputation 6.0 p.m. May 2. Examination of bone 2.0 p.m. May 3. Sepsis before amputation, 5 days. Duration of post-mortem growth, 21 hours.

Lesion.—Open septic knee-joint, with bruise of external condyle of femur, but no fracture (*Fig.* 244.)

Table 22.—*Case* 2.

Specimen taken for Culture	Distance from Source of Infection	Aerobic Bacteria	Anaerobic Bacteria
Femur 1	6·2 cm.	Streptococcus, *B. pyocyaneus*, *B. proteus*	0
,, 2	13·3 ,,	,, ,,	+ (including *B. perfringens*)
,, 3	14·0 ,,	,, ,,	+
,, 4	13·5 ,,	,, ,,	+

Conclusion.—In 21 hours, growth to at least 10 cm.; limit not reached.

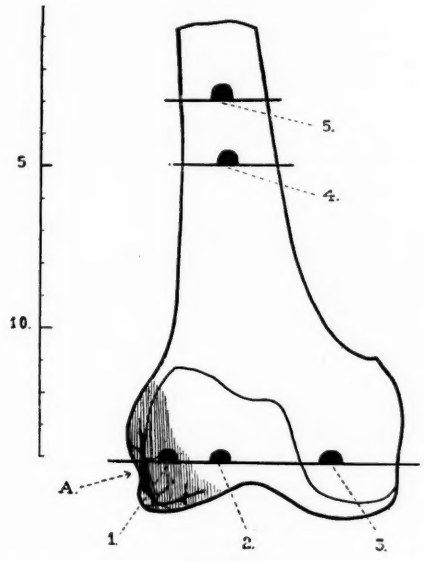


Fig. 243.

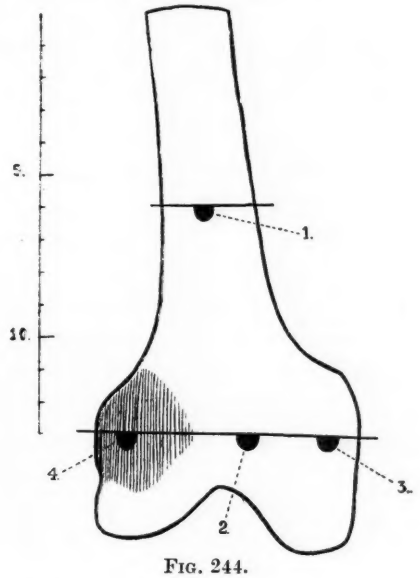


Fig. 244.

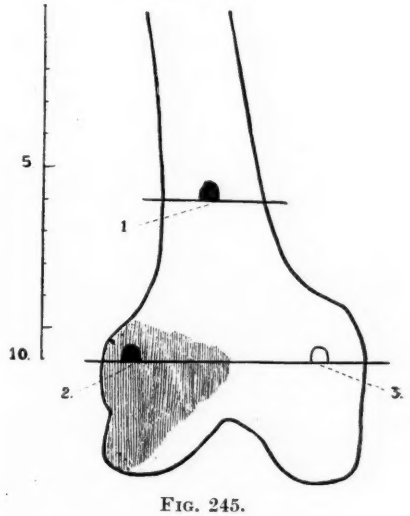


Fig. 245.

Fig. 243.—*Case* 1. Lower end of femur with fracture and bruise of external condyle. Cut surface soiled by pus from wound. Post-mortem growth from both ends in 28 hours at room temperature.

Fig. 244.—*Case* 2. Lower end of femur with bruise of external condyle, but no fracture. Cut surface soiled by pus from wound. Post-mortem growth from cut end to 10 cm. in 21 hours at room temperature.

Fig. 245.—*Case* 3. Lower end of femur with bruise of external condyle but no fracture. Cut end soiled by pus from wound. Post-mortem growth from cut end to 10 cm. in 28½ hours at room temperature.

Case 3.—L.-Cpl. C. Date of wound not known. Amputation 11.0 a.m. May 5, 1916. Examination of bone 6.0 p.m. May 6. Sepsis before amputation: duration not known. Duration of post-mortem growth, 28½ hours.

Lesion.—Open septic knee-joint, with bruise of external condyle of femur, but no fracture (*Fig.* 245.)

Table 23.—*Case* 3.

Specimen taken for Culture	Distance from source of Infection	Aerobic Bacteria	Anaerobic Bacteria
Femur 1	5·3 cm.	Streptococcus	0
,, 2	11·0 ,,	0	0
,, 3	11·3 ,,	Streptococcus	0
Knee-joint	..	Streptococcus, staphylococcus	–

Conclusion.—In 28½ hours, growth to 10 cm.; limit reached (*Table* 23). Growth has extended further in the bruised than in the normal condyle, probably because the effused blood is a medium specially suited to the streptococcus.

These three bones show so extensive a penetration by organisms as to arouse suspicion of post-mortem growth. This suspicion has been confirmed by the results of examination of fresh material of corresponding type obtained by operation. Thus, the average distance of penetration of the streptococcus in fresh material has been found to be 2 cm., contrasting with an average distance of 8 cm. (limit not reached in two of the cases) for these three bones.

Effect on Penetration of the Circulatory Conditions Preceding Death (*Cases* 4, 5).

Case 4.—Lieut. B., age 21. Extensive saprophytic invasion of bone, associated with terminal circulatory failure.

Table 24.—*Case* 4.

Specimen taken for Culture	Distance from Lesion	Aerobic Bacteria	Anaerobic Bacteria
Femur 1 ..	2·2 cm.	Streptococcus, *B. coli*	+
,, 2 ..	4·4 ,,	Streptococcus, mixed growth	+
,, 3 ..	6·7 ,,	Streptococcus, mixed growth	+
,, 4 ..	9·0 ,,	Mixed growth	+
,, 5 ..	14·0 ,,	,, ,,	+
,, 6 ..	18·8 ,,	Streptococcus, mixed growth	+
,, 7 ..	24·3 ,,	Streptococcus, staphylococcus, coliform bacilli	+
Blood culture 31 hours before death	..	0	0

Ante-mortem exposure of bone to sepsis.—10 days.
First culture taken from bone.—35 minutes after death.
Last culture taken from bone.—1 hour 25 minutes after death.
Order of cultures.—7, 6, 5, 4, 3, 2, 1.

Clinical History.—Wounded Sept. 19, 1916. Compound fracture of fibula. Amputation in lower third of thigh for gas gangrene at casualty clearing station, Sept. 19. Flaps stitched. Stitches removed at end of four days and pus evacuated. Gradual failure of circulation for three days before death, with frequent vomiting and sweats. Death 10.0 p.m. Sept. 29.

For the last forty-eight hours the extremities were cold and blue, and the radial pulse was absent, but patient was quite conscious. The stump was distended with extreme œdema and a moderate quantity of gas. There was no jaundice or local bronzing of the skin.

Clinical Picture.—Toxic failure of circulation. (*Figs.* 246, 247, and *Table* 24.)

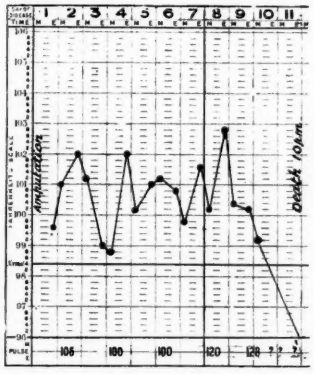


FIG. 246.—*Case* 4. Death from gas-gangrene toxæmia. Terminal failure of circulation.

Case 5.—Lieut. K., age 27. Absence of saprophytic invasion, associated with maintenance of the circulation till death.

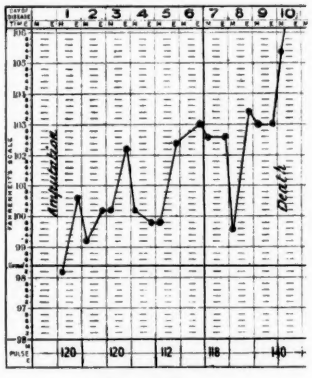


FIG. 248.

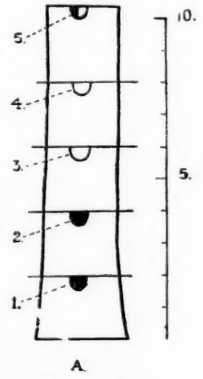


FIG. 249.

FIG. 248.—*Case* 5. Death from streptococcal septicæmia. Absence of terminal failure of circulation.

FIG. 249.—*Case* 5. 10 cm. of shaft of tibia from case dying of streptococcal septicæmia after amputation (A). Absence of any considerable penetration by organisms when circulation is maintained to the end. Growth at (5) of septicæmic origin.

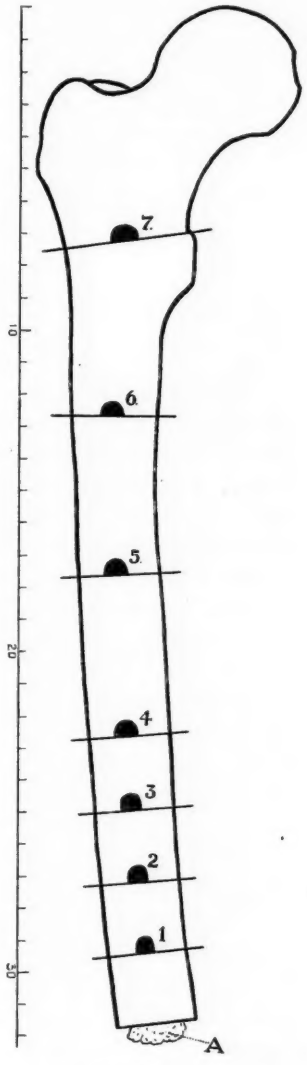


FIG. 247.—*Case* 4. Upper 32 cm. of femur from patient dying of gas gangrene after amputation. Penetration by organisms to 24 cm. accompanying terminal failure of circulation. A, Amputation.

Clinical History.—Wounded Feb. 8, 1917. Left foot shattered by shell. Amputation in lower third of leg, Feb. 9. Flaps stitched. Stitches removed after twenty-four hours. Œdema of leg up to knee. Death Feb. 18, 11.20 a.m.

Clinical Picture.—Septicæmia. (*Figs.* 248, 249, and *Table* 25.)

Table 25.—*Case* 5.

Specimen taken for culture	Distance from lesion	Aerobic bacteria	Anaerobic bacteria
Tibia 1	1·5 cm.	Streptococcus, staphylococcus, *B. coli*	+
,, 2	3·5 ,,	Streptococcus, staphylococcus	0
,, 3	5·5 ,,	0	0
,, 4	7·5 ,,	0	0
,, 5	10·0 ,,	Streptococcus	0
Blood culture 18½ hours before death	..	,,	—

Ante-mortem exposure of bone to sepsis.—9 days.
Bone in ice.—From 11.50 a.m. to 5.45 p.m.
First culture taken from bone.—5.50 p.m.
Last culture taken from bone.—6.10 p.m.
Order of cultures.—5, 4, 3, 2, 1.

From a comparison of these two cases, it is seen that the condition of the peripheral circulation before death has an important bearing on the bacteriological findings. In *Case* 4, the prolonged failure of circulation which preceded somatic death is reflected in the temperature chart with its terminal fall, in the absence of radial pulse, in the anaerobic cellulitis of the stump, and in the extension of organisms throughout the whole length of the femur (see *Table* 24). The bone is, in fact, comparable in its absence of resistance to infection to *Cases* 1, 2, and 3, and the growth of organisms is in reality a post-mortem phenomenon occurring during life.

In *Case* 5, where death from streptococcal septicæmia was accompanied by a terminal rise of temperature and maintenance of the peripheral circulation up to the end, the circulatory conditions in the bone-marrow of the stump remained practically constant till death. In this bone, although the length of exposure to sepsis was the same as that of the previous case, organisms grew up only 4 cm. from the cut end (see *Table* 25). The growth at Section 5 is of septicæmic origin, while the absence of growth at Sections 3 and 4 can best be explained by the assumption that the septicæmia had not long been established.

In drawing deductions from observations on bones removed at autopsy, therefore, due consideration must be given to the clinical picture of the case before death. Material obtained at operation is free from this necessity for analysis, and conclusions may be drawn from it with greater directness and less error of interpretation. With the exception of the two bones just referred to, the whole of the material was obtained by operation.

Additional Examples of Penetration through Normal Bone (*Cases* 6, 8).

Case 6.—L.-Cpl. A. [*Ref. No.* 201.] Amputation through normal cancellous tissue.

Clinical History.—Wounded April 22, 1916. Flapless amputation 5 cm. below knee at casualty clearing station before April 26 (exact date not known). Upper end of fibula removed. Streptococcal infection of knee-joint through popliteus bursa. Re-amputation above knee at base, 12.30 p.m. May 12. (*Fig.* 250.)

Table 26.—*Case* 6.

Specimen taken for culture	Distance from lesion	Aerobic bacteria	Anaerobic bacteria	Direct smear
Tibia 1	0·5 cm.	Streptococcus, staphylococcus	0	0
„ 2	1·5 „	Streptococcus, staphylococcus	0	0
„ 3	4·0 „	0	0	0
Knee-joint	..	Streptococcus	0	Very few cocci
Femur, cancellous tissue (control)		0	0	
Femur, medulla (control)	..	0	0	

Exposure of bone to sepsis.—16 to 20 days.
First culture taken from bone.—2½ hours after amputation.
Last culture taken from bone.—3½ hours after amputation.
Order of cultures.—Femur. Tibia : 3, 1, 2.

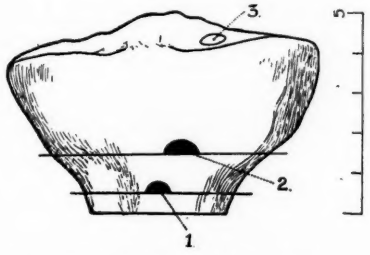


Fig. 250.—*Case* 6. Tibia from flapless amputation exposed to infection 16 to 20 days. Growth to 1·5 cm. from cut surface.

Case 8.—Lieut. M., age 23. [*Ref. No.* 203.]

Lesion.—Penetrating shell-wound of knee. Small fracture of articular surface of internal condyle of femur, with tear of semilunar cartilage. No injury to tibia.

Clinical History.—Wounded Aug. 22, 1916. Shell fragment removed at casualty clearing station Aug. 24. Arrived at base Aug. 27. Knee distended : aspiration —pus—streptococcus. Resection of knee-joint Aug. 28. Persistent œdema of leg. Amputation for sepsis Sept. 20, 2.35 p.m. Transferred to England Oct. 1.

Examination of Limb after Removal, Sept. 20.—Leg œdematous ; pus behind head of tibia ; carious patch, not covered by granulations, on sawn surface of internal tibial tuberosity. No other pus collection in leg. (*Fig.* 251 and *Table* 27.)

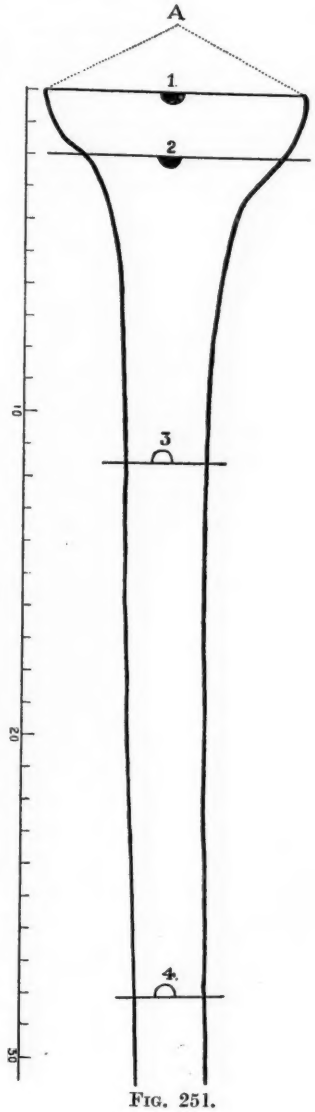


Fig. 251.

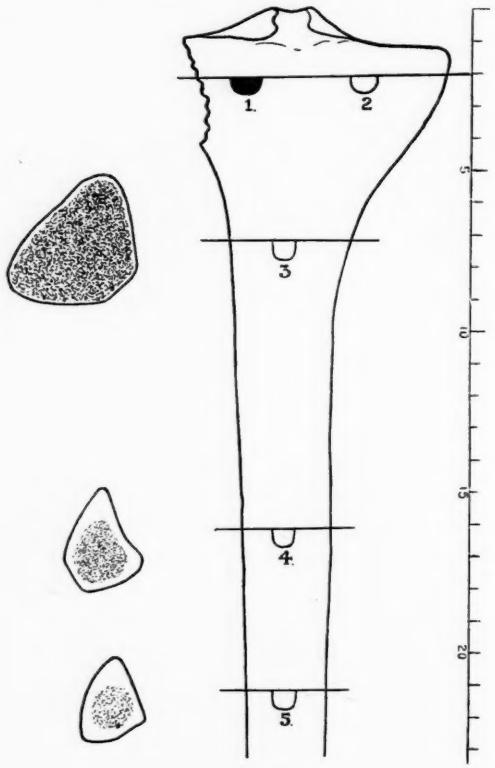
Fig. 251.—*Case* 8. Tibia removed by amputation 23 days after resection of knee-joint, showing penetration to 2 cm. in normal bone. (*Cf. Figs.* 250, 212, 214.)

Table 27.—*Case* 8.

Specimen taken for Culture	Distance from Lesion	Aerobic Bacteria	Anaerobic Bacteria
Tibia 1	Surface	Streptococcus, staphylococcus	0
„ 2	2·0 cm.	Streptococcus	0
„ 3	11·2 „	0	0
„ 4	27·7 „	0	0
Femur 2 cm. from resected surface	..	Streptococcus	0
Pus from wound	..	Streptococcus, staphylococcus	0
Blood from vein at amputation	..	0	—

Exposure of bone to sepsis between resection and amputation.—23 days.
Bone in ice.—From 2.35 p.m. to 3.0 p.m.
First culture taken from bone.—3.0 p.m.
Last culture taken from bone.—4.0 p.m.
Order of cultures.—Tibia : 4, 3, 1, 2. Femur.

Note.—Tibia 2 is probably near the limit of penetration, because only the sample grown aerobically yielded streptococcus, whereas the anaerobic culture of tibia 1 grew streptococci and staphylococci.



Fig, 252.

Illustrations of Low Penetrating Power of B. Coli (*Cases* 9, 10).—In *Case* 9, well-drained bone was exposed in a septic flesh-wound into which a continuous feed of *B. coli* was maintained from the comminuted head of the fibula and the knee-joint. In *Case* 10, the fracture had originally been opened up, but the wound was allowed to close until drainage was reduced to that afforded by a narrow sinus.

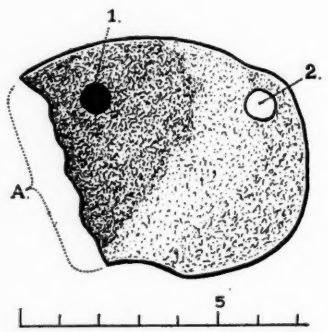


Fig. 253.

Fig. 252.—*Case* 9. Tibia removed by amputation 14 days after injury. Shell fracture of external tuberosity. Penetration of *B. coli* did not reach limits of bruise. Section 3 bruised.

Fig. 253.—*Case* 9. Transverse section of tibia shown in *Fig.* 252 at level of (1) and (2). A, Fracture.

Case 9.—Lieut. B., age 22. [*Ref. No,* 204.]

Lesion.—Compound fracture of head of fibula and external tuberosity of tibia by high-explosive shell.

Clinical History.—Wounded June 17, 1916, 9.0 p.m. No operation at casualty clearing station. First operation at base on admission, June 19, 10.30 p.m. Wound foul, with local gas infection of muscle. Wide resection, knee-joint open. Knee-joint aspirated June 26: pus, *B. coli.* Amputation above knee July 1, 2.45 p.m., for suppurative arthritis. Transferred to England July 21.

Examination of Limb, July 1.—Joint-fluid: viscid, yellow pus. Synovial membrane: thickened. Articular cartilage: soft and eroded. Tibia: bruised bone of external tuberosity, softened and grey on surface. (*Figs.* 252, 253.)

Table 28.—*Case* 9.

Specimen taken for Culture	Distance from Lesion	Aerobic Bacteria	Anaerobic Bacteria
Tibia 1	0·8 cm.	*B. coli*	+ (including *B. perfringens*)
,, 2	4·7 ,,	0	0
,, 3	3·8 ,,	0	0
,, 4	12·3 ,,	0	0
,, 5	17·3 ,,	0	0
Femur (control)	..	0	0
Knee-joint, June 20 ..	..	0	0
,, June 26 ..	..	*B. coli*	0
,, July 1 ..	..	,,	0
Blood from vein, July 6	..	0	—

Exposure of bone to sepsis before amputation.—14 days.
Tibia in ice.—From 2.45 p.m. to 6 p.m.
First culture taken from tibia.—6.20 p.m. Last culture.—6.45 p.m.
Order of cultures.—Tibia: 4, 2, 1, 3, 5.
Femur in ice.—From 2.45 p.m. to 7.40 p.m.
Culture taken from femur.—7.50 p.m., 1 cm. beneath erosion of articular cartilage.

Case 10.—Pte. L. [*Ref. No.* 205.]

Lesion.—Penetrating side-to-side high-explosive shell wound of outer aspect of knee-joint, with fracture of posterior part of external condyle of femur.

Table 29.—*Case* 10.

Specimen taken for Culture	Distance from Lesion	Aerobic Bacteria	Anaerobic Bacteria
Femur 1	0·5 cm.	*B. coli*	0
,, 2	1·8 ,,	0	0
,, 3	2·8 ,,	0	0
,, 4	3·8 ,,	0	0
,, 5	8·5 ,,	0	0
Tibia (control)	..	0	0
Knee-joint	..	*B. coli*, staphylococcus	0

Exposure of bone to sepsis.—21 days.
Amputation.—11 a.m.
Culture from joint.—2 p.m.
First culture taken from bone.—3.0 p.m. Last culture.—4.30 p.m.
Order of cultures.—Femur: 5, 4, 3, 2, 1. Tibia.

Clinical History.—Wounded April 26, 1916. Lateral incisions for drainage of septic knee on either side of patella. Original wound on outer side of joint enlarged and shell removed. Thomas knee-splint with strapping extension. Amputation for continued sepsis.

Examination of Limb, May 17, 2.0 p.m.—Lateral incisions for drainage granulating and no longer communicating with joint cavity. Moderate distention of knee by blood-stained fluid, which discharged through small sinus in centre of granulating original wound. Early erosion of articular cartilage. Synovial membrane intensely injected. No extracapsular extension of pus. Popliteal vessels intact. Tibia uninjured. (*Figs.* 254, 255, and *Table* 29.)

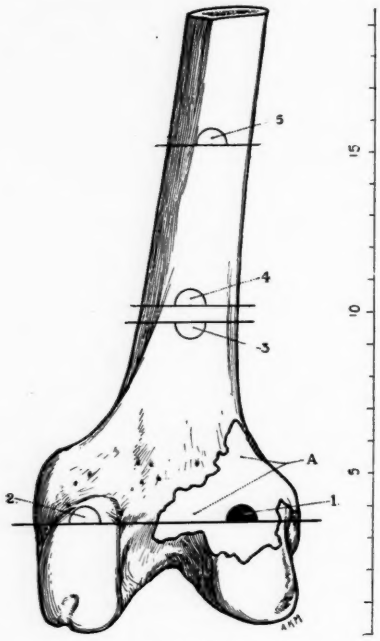


FIG. 254.

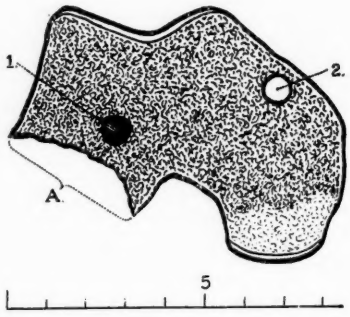


FIG. 255.

FIG. 254.—*Case* 10. Lower end of femur removed by amputation 21 days after injury. A, Foul wound of upper and back part of external condyle. Penetration slight, probably on account of nature of infection (*B. coli*).

FIG. 255.—*Case* 10. Transverse section of femur shown in *Fig.* 254 at level of (1) and (2).

Additional Examples of Extensive Penetration Associated with Interruption of the Medullary Artery (*Cases* 15, 16).

Case 15.—Capt. S., age 28.
Lesion.—Rifle-bullet fracture of middle of shaft of femur.

Table 30.—*Case* 15.

SPECIMEN TAKEN FOR CULTURE	DISTANCE FROM LESION	AEROBIC BACTERIA	ANAEROBIC BACTERIA
Upper fragment 5 ..	3·4 cm.	Streptococcus	0
Lower ,, 1 ..	In fissure	,,	+
,, ,, 2 ..	Limit of fissure	,,	+
,, ,, 3 ..	2·1 cm.	,,	+
,, ,, 4 ..	7·8	,,	+
Blood from vein, Nov. 9	..	,,	0

Exposure of bone to sepsis.—42 days.
Bone in ice.—From 9.45 p.m. to 10.25 p.m.
First culture taken from bone.—10.40 p.m.
Last culture taken from bone.—11.0 p.m.
Order of cultures.—Lower fragment: 4, 3, 2, 1. Upper fragment: 5.

Clinical History.—Wounded Sept. 29, 1916. Left out thirty hours. Septic from commencement. Tube drainage established at casualty clearing station. Severe secondary hæmorrhage Nov. 9, forty-one days after original injury, when union was commencing. Blood transfusion, followed by amputation, Nov. 10, 9.45 p.m. Pneumonia. Death, Nov. 14.

Examination of Limb after Removal, Nov. 10.—Entry wound on outer side. Pocket of pus on inner side of femur beneath vastus internus. Hæmorrhage from small undetermined artery. Consolidation commencing in fracture; healthy-looking callus from bone ends. No appearance of inflammation of bone away from fracture.

Clinical Picture.—Septicæmia. (*Fig.* 256 and *Table* 30.)

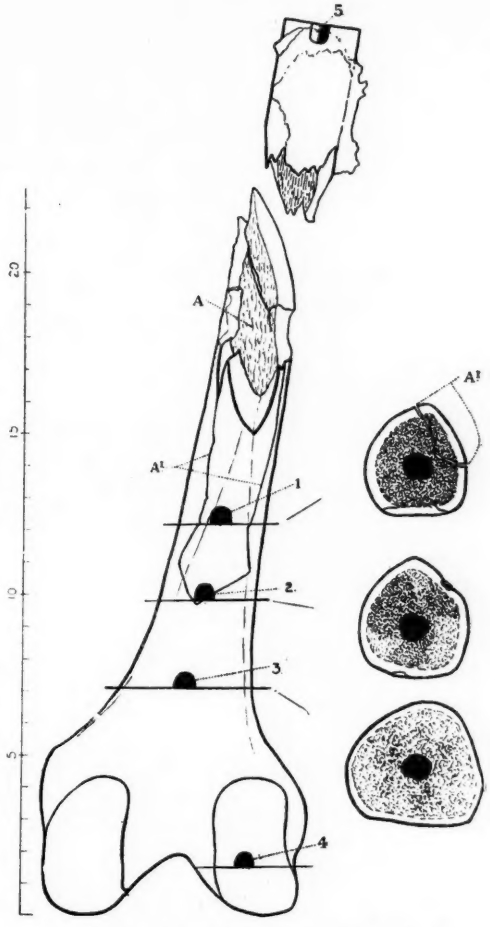


Fig. 256.—*Case* 15. Upper and lower fragments of fractured femur removed by amputation 42 days after injury and 24 hours after severe secondary hæmorrhage. Penetration of whole lower fragment by anaerobes associated with interruption of medullary artery.

The interpretation of *Case* 15 is complicated by the interval of twenty-four hours between the hæmorrhage and the amputation. It is conceivable that, in consequence of the diminution of the general circulation which followed the hæmorrhage, penetration of anaerobes was facilitated during this interval.

Case 16, although no opportunity of examining the upper fragment offered, is useful as a control on this point, since only forty-five minutes elapsed between secondary hæmorrhage and amputation. In other respects it is identical with *Case* 15.

Case 16.—Lieut. C., age 21.

Lesion.—Compound comminuted fracture of shaft of femur.

Clinical History.—Perforating wound, just above middle of thigh, opened up at casualty clearing station. Condition on admission to base hospital Nov. 3, 1916, one of collapse. Severe secondary hæmorrhage Nov. 4, 10.0 a.m. Amputation Nov. 4, 10.30 a.m. Recurrence of hæmorrhage from stump. Death Nov. 6, 1.30 a.m.

Clinical Picture.—Septicæmia.

Examination of Limb after Removal, Nov. 4.—Muscle of limb normal in appearance except in immediate neighbourhood of fracture; no gas. (*Fig.* 257 and *Table* 31.)

In view of the similarity of the bacteriological findings in *Cases* 15 and 16, no stress can be laid on the possibilities of penetration being accentuated by loss of blood during the twenty-four hours which followed the hæmorrhage in

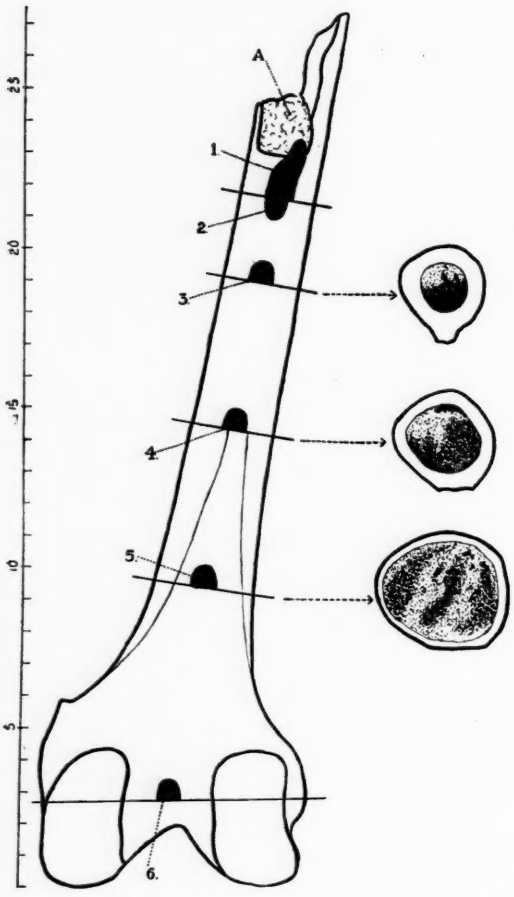


FIG. 257.—*Case* 16. Lower fragment of femur removed by amputation 7 days after injury and immediately after severe secondary hæmorrhage. Penetration of whole lower fragment by anaerobes. Control on *Fig.* 256.

the former. From the nature of the cases it is difficult to draw any conclusion from them of the effects of secondary hæmorrhage. The bones can only be examined after either amputation or death. Amputation, if performed at all, is usually done immediately, and no opportunity occurs for any possible effects of the hæmorrhage to develop. If the bone were examined after death, such effects could not certainly be dissociated from those of the terminal failure of circulation.

Table 31.—*Case* 16.

SPECIMEN TAKEN FOR CULTURE	DISTANCE FROM LESION	AEROBIC BACTERIA	ANAEROBIC BACTERIA
Femur 1	Surface	Streptococcus	+ (including *B. perfringens*)
,, 2	1·3 cm.	,,	+ ,, ,,
,, 3	3·3 ,,	,,	+ ,, ,,
,, 4	8·0 ,,	,,	+ ,, ,,
,, 5	13·0 ,,	,,	+
,, 6	19·7 ,,	,,	+
Tibia, cancellous bone (control)	..	,,	0
Tibia, medulla of shaft (control)	..	,,	0
Blood from vein $1\frac{3}{4}$ hours after amputation	..	,,	0

Exposure of bone to sepsis.—7 days.
Bone in ice.—From 11.10 a.m. to 2.30 p.m.
First culture taken from bone.—2.30 p.m.
Last culture taken from bone.—3.5 p.m.
Order of cultures.—Tibia : 1, 2. Femur : 6, 5, 4, 3, 2, 1.

Additional Examples Illustrating (1) Early, and (2) Late Stages of Penetration in Untreated Septic Fractures (*Cases* 18, 20).

1. EARLY STAGE.

Case 18.—Lieut. O., age 23. [*Ref. No.* 209.]

Lesion.—Penetrating wound of external condyle of femur. High-explosive shell fragment and cloth embedded in cancellous bone.

Clinical History.—Wounded July 2, 1916. Severe multiple wounds by high-explosive shell. No surgical interference between infliction of wound and resection of knee-joint. Entry wound over most prominent part of condyle—i.e., very short track in soft parts.

Operation, July 5, 4.30 p.m.—Wound excised. External condyle cut away down to shell fragment. Subjacent bone black and foul-smelling, with crack into joint. Resection. Joint effusion: blood-stained, sterile. Transferred to England July 27.

Examination of Bone Removed, July 5.—External condyle deeply bruised, and separated from rest of bone by complete fissure. (*Figs.* 258, 259.)

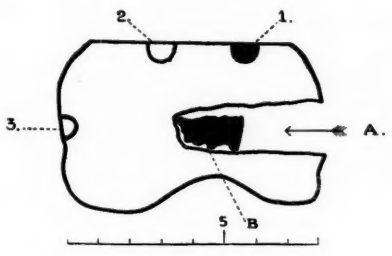


FIG. 258.

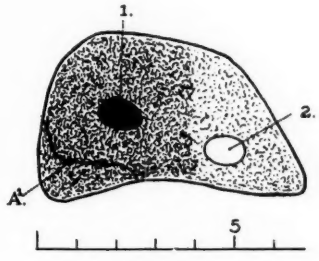


FIG. 259.

FIG. 258.—*Case* 18. Lowe extremity of femur removed by operation 3½ days after injury (diagrammatic), showing shell fragment embedded, and penetration to 0·8 cm. by anaerobes.

FIG. 259.—*Case* 18. Tracing from upper surface of resected lower end of femur shown in *Fig.* 258, to show fissure, bruise, and degree of penetration in early untreated fracture.

Table 32.—*Case* 18.

SPECIMEN TAKEN FOR CULTURE	DISTANCE FROM LESION	AEROBIC BACTERIA	ANAEROBIC BACTERIA
Femur 1	0·8 cm.	0	+
„ 2	1·9 „	0	0
„ 3	3·1 „	0	0
Knee-joint at operation	..	0	0

Exposure of bone to sepsis.—3½ days.
Resection.—4.30 p.m.
Bone in ice.—From 4.30 p.m. to 5.35 p.m.
First culture taken from bone.—6.0 p.m.
Last culture taken from bone.—6.40 p.m.
Order of cultures.—2, 1, 3.

2. LATE STAGE.

Case 20.—Pte. A. [*Ref. No.* 210.] Amputation in lower third of thigh for suppurative arthritis of knee.

Examination of Limb after Removal.—Vertical incision 5 inches long on either side of knee, opening joint and exposing condyles. Original shell-entry on inner side. Œdema of leg. No injury to tibia and fibula.

Bone: Foul débris *in situ*; fracture into joint; transverse pus-track between femur and subcrureal bursa, probably a tube track.

Knee-joint: Widely open; articular cartilage softened; synovial membrane sloughing; purulent effusion. Extracapsular extension of pus, commencing from popliteus bursa. (*Figs.* 260, 261.)

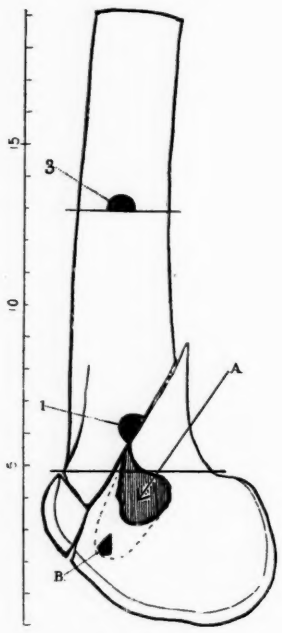


FIG. 260.

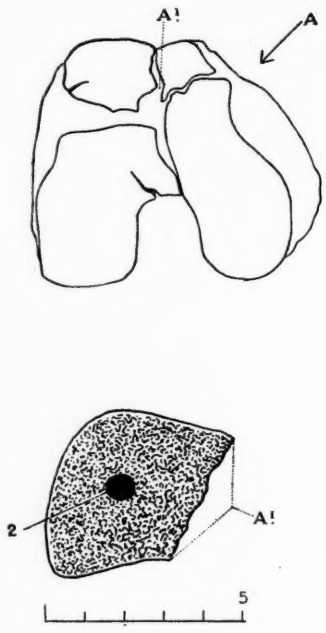


FIG. 261.

FIG. 260.—*Case* 20. Femur removed by amputation for shell fracture (A) of internal condyle. No surgical interference with actual fracture. Growth throughout bone.

FIG. 261.—*Case* 20. Femur shown in *Fig.* 260 from below to indicate fissure (A^1) separating internal condyle from rest of bone. Below is transverse section just above condyles to show penetration from fissure A^1.

Table 23.—*Case* 20.

SPECIMEN TAKEN FOR CULTURE	DISTANCE FROM LESION	AEROBIC BACTERIA	ANAEROBIC BACTERIA
Femur 1	Surface	*B. coli*, staphylococcus	+ (including *B. perfringens*)
,, 2	1·5 cm.	Staphylococcus	0
,, 3	5·0 ,,	*B. coli*, streptococcus	0

Amputation.—12.30 p.m., June 28, 1916.
Limb in ice.—From 1 p.m. to 3.5 p.m.
First culture taken from bone.—4 p.m.
Last culture taken from bone.—4.30 p.m.
Order of cultures.—2, 1, 3.

APPENDIX II.

CULTURAL REACTIONS OF STAPHYLOCOCCI AND COLIFORM BACILLI ISOLATED FROM BONE.

Table 34.—Showing the Cultural Characters of Types of *B. coli* Isolated from Bones.

Source	Type	Saccharose	Dulcite	Glucose	Mannite	Lactose	Litmus Milk	Gelatin Liquefaction	Indol	Motility
Case 24: Tibia 1 (and knee-joint)	Group I	0	0	AG	AG	AG	AC	0	0	0
Lt. G.: Radius and humerus	,, II	0	AG	AG	AG	AG	A	0	+	+
Case 10: Femur 1 (and knee-joint)	,, III	AG	AG	AG	AG	AG	AC	0	+	+
Case 19: Tibia 1 (and knee-joint)	,, ,,	AG	AG	AG	AG	AG	A	0	+	0
Case 4: Femur 1	,, ,,	AG	AG	AG	AG	AG	AC	0	+	+
Case 5: Tibia 1	,, ,,	AG	AG	AG	AG	AG	AC	0	0	+
Case 20: Femur 1 and 3	,, IV	AG	0	AG	AG	AG	AC	0	0	+
Case 27: Femur 1	,, ,,	AG	0	AG	AG	AG	A	0	0	+

A = Acid. AG = Acid and gas. AC = Acid and clot. 0 = Absence of reaction.

Table 35.—Showing the Distribution of *B. coli* from a Variety of Sources.

Type	Bone	Soil	Cesspool Sewage	Human Fæces	Horse, Calf, and Pig Fæces
Group I	1	2	4	62	9
,, II	1	0	1	49	33
,, III	4	10	1	61	68
,, IV	2	4	0	16	4

Note.—The figures represent the actual number of strains isolated.

The cultural reactions of 20 strains of staphylococcus isolated from freshly-examined material have been tested as far as possible. Of these, 15 strains from 15 samples of bone, taken for culture from 8 patients, gave the following reactions: acidity in glucose, lactose, mannite, and saccharose; acidity and clot in milk; and liquefaction of gelatin. Five strains failed to liquefy gelatin, and two produced no acidity in mannite. None of the cultures showed any marked pigment production.

The cultural characteristics of a number of *B. coli* isolated from bones are arranged in *Table* 34, in the grouping suggested by MacConkey for the differentiation of coliform bacilli on the basis of their ability to ferment saccharose and dulcite.*

Utilizing the data of this writer for the distribution of the four types in various materials (*Table* 35), and having regard to the limited sampling in some of the cases, it appears that the figures are at least significant of the source of the *B. coli* cultivated from bones, since the closest correlation exists between these strains and those recovered from the soil.

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* A. T. MacConkey, "Further Observations on the Differentiation of Lactose-fermenting Bacilli, with special reference to those of Intestinal Origin," *Jour. of Hygiene*, ix, 86.

SHORT NOTES OF RARE OR OBSCURE CASES.

NOTE ON A CASE OF PEPTIC ULCER OPENING INTO THE TRANSVERSE COLON.

By GILBERT BARLING, Birmingham.

I performed gastrojejunostomy on a patient, age 54, in April, 1914. The symptoms of duodenal ulcer had existed for about four years previously, with intermissions. The pain came on two or three hours after food as a rule, but it might be continuous; it was often extremely troublesome at night. Vomiting had not occurred, and melena had not been observed. A rather acutely tender spot existed in the epigastrium a little above the mid-point between the umbilicus and the tip of the ensiform cartilage; there was also complaint of tenderness over the cæcum.

Fig. 262.—Skiagram showing communication between jejunum and transverse colon.

At the operation, the duodenum showed a cicatrix three-quarters of an inch beyond the pylorus; and extending from that point to the second portion of the duodenum was an ulcer of considerable extent, with a good deal of thickening around. A no-loop trans-mesocolic gastrojejunostomy was made. For the inner row of sutures catgut, and for the outer row thread, was employed; the pylorus was puckered with a purse-string suture; and the appendix, tied down by old adhesions, was removed, as was a band of old adhesion running from the apex of the gall-bladder towards the middle of the great omentum.

The patient made a good recovery, and was well until October, 1915, when he suffered a good deal of discomfort after food, this coming on after a period of overwork and exposure to chill. By rest, dieting, and alkalies this condition disappeared, but it created a suspicion at the time that the patient was suffering from a peptic ulcer near the point of anastomosis.

I did not see the patient again until February, 1917, when I was home on leave from France. I then learnt that in the summer of 1916 he went to work on the land, and about October suffered from severe abdominal pain and vomiting; the vomit was described as actually fæcal, and was associated with diarrhœa. The patient wasted rapidly, but although he was suffering from vomiting and diarrhœa, he was constantly hungry. For some time he took only fluid diet, but as his appetite was good, he was eventually put on solid food. This appeared to suit him better; vomiting disappeared, and the diarrhœa also, and at this time examination of the motions failed to detect undigested food. At varying intervals the vomiting and diarrhœa recurred, and later a phlebitis of the left femoral vein arose.

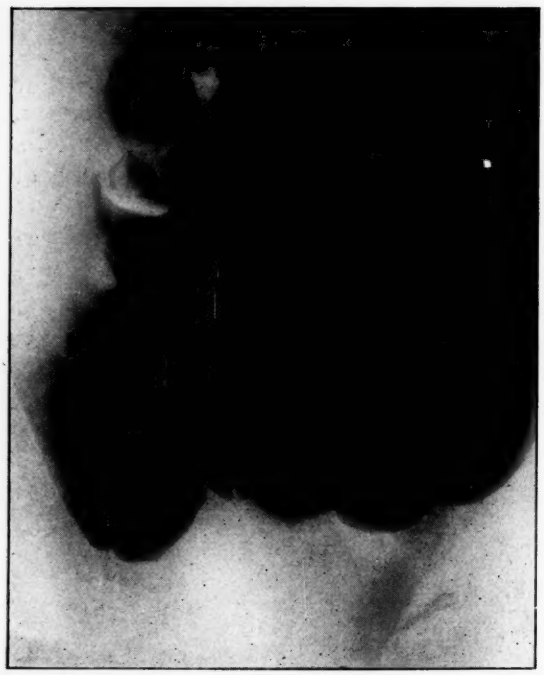

FIG. 263.—Skiagram showing communication between jejunum and transverse colon.

On examining the abdomen at this time (February), I could not detect any particular tenderness, but there was a general appearance of abdominal fullness, as though the intestinal tract were distended; the patient looked thin, but not ill. The diagnosis made at this time was that a communication existed between the stomach and colon or between the colon and jejunum, probably the latter. Operation was considered, but was not entertained, owing to the prospect that a very severe procedure would be required—probably excision of a portion of the colon, excision of the existing anastomosis, and a re-anastomosis.

I did not see the patient again until June 22, when I learnt that since my last interview he had had various ups and downs, sometimes taking solid food and having natural motions, at other times suffering from vomiting and diarrhœa. Wasting was rather extreme, and there was a curious patchy œdema about the patient, chiefly on the legs and abdominal wall, but there did not appear to be any dropsy of the abdomen. At this time I secured a radiographic report from Dr. Black, as follows:—

Radiographic Report.—A meal consisting of 12 oz. pudding, and containing 5 oz. barium sulphate, was eaten. This was watched as it passed into the stomach, and it was seen to pass directly through the gastrojejunostomy opening without any delay. The course of the meal was then difficult to follow. Part of it appeared to travel downwards on the left side in the line of the descending colon. It was not possible to say whether it was actually in the colon, or whether it was in dilated small intestine. Another part of the meal travelled to the right, apparently along the line of the transverse colon towards the hepatic flexure, and within ten minutes of eating the cæcum was seen to be filled.

Two prints of the negatives accompany this note (*Figs.* 262, 263), confirming the diagnosis of a communication between the stomach and colon or jejunum and colon.

In view of the patient's general condition, operation was not entertained, and the end came on July 6, 1917. Early that day the patient was seized with intense abdominal pain, and died the same evening. The diagnosis made was perforative peritonitis.

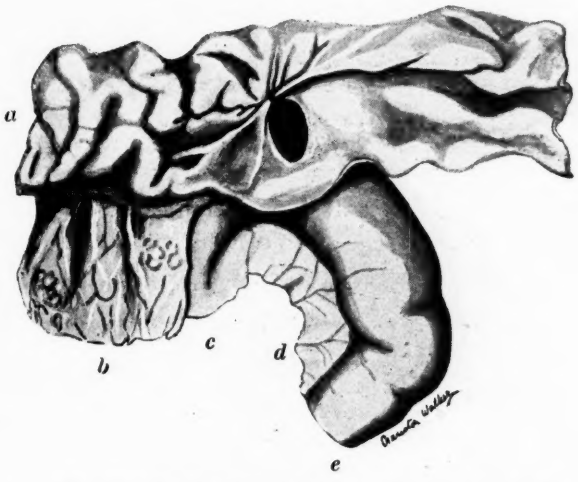

FIG. 264.—Showing the opening leading from the transverse colon into the jejunum. *a*, Transverse colon, laid open; *b*, Omentum; *c*, Duodenum; *d*, Mesentery; *e*, Jejunum.

At the autopsy, there was general peritonitis, with a considerable amount of turbid fluid in the abdomen which arose from a leakage of an ulcer in the jejunum behind the transverse colon. Investigation of the parts involved showed that the junction of the stomach with the jejunum was a good one; the opening was two inches in diameter, and the margin perfectly sound. On the mesenteric border of the jejunum, immediately opposite the gastro-jejunostomy opening, there was an ulcer about five-eighths of an inch in diameter, but not very deep in most of its extent. The ulceration spreading from this had opened into the transverse colon, where there was a communication about half an inch in diameter between the jejunum and colon; the margins of this opening were perfectly healed and smooth.

The drawing (*Fig.* 264), for which I am indebted to Dr. Cranston Walker, shows the transverse colon laid open, with the healed peptic ulcer in the colic wall; the opening shown goes straight into the jejunum near the point of anastomosis with the stomach.

INSTRUCTIVE MISTAKES.

A COMPENSATION CASE, IN WHICH THE MARKINGS OF THE NUTRIENT CANALS OF THE ILIUM WERE MISTAKEN FOR FRACTURE: OF INTEREST FROM AN X-RAY POINT OF VIEW.

By Staff-Surgeon A. K. SMITH-SHAND, R.N.

B. P., age 29, shipwright, reported sick about the first week in March, 1915, in his ship, complaining of pain in the left gluteal region. This he attributed at the time to "getting his bedding wet" by sea-water. After twelve days' treatment he returned to full duty. Six weeks later he was confined

Fig. 265.—Skiagram similar to the one taken in the provincial hospital, showing only one arm of the V, which was mistaken for a fracture. (The arrows in *Figs.* 265, 266, and 267 point to the markings of the nutrient canals.)

to his hammock for ten days on account of the pain. From May till August he was again at full duty, until discharged to a naval hospital with similar symptoms. He remained under treatment in hospital till Nov. 22, when he was discharged to light duty. He again went sick in January, 1916, and after treatment in the same hospital, was finally invalided out of the Service

FIG. 266. — Showing characteristic V-shaped mark on the side of the alleged fracture.

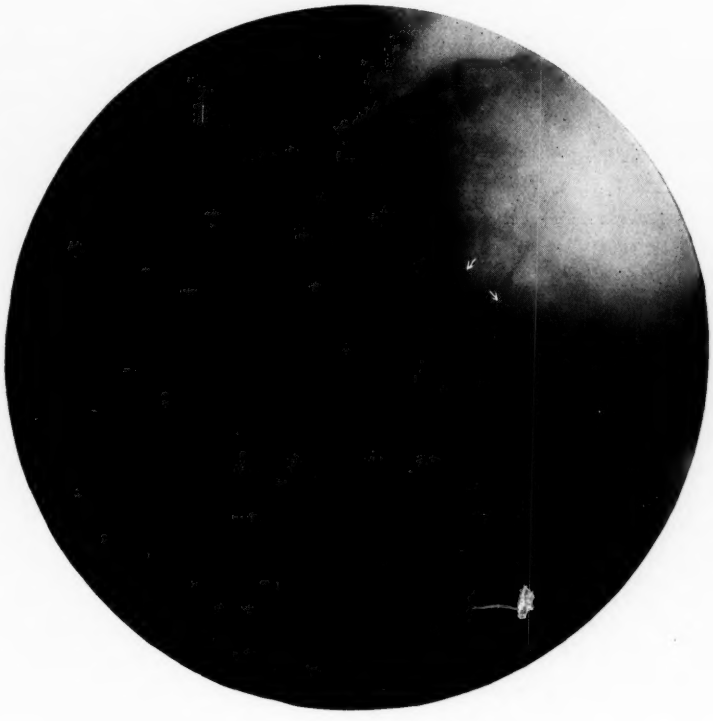

FIG. 267. — Similar mark seen in ilium on side opposite to the alleged fracture.

on Feb. 4. The diagnosis of his condition was sciatica, and the Board of Survey made his case " not attributable to the Service."

Shortly after his discharge from the navy the man attended a provincial hospital, where he received treatment in the form of massage and exercises. He there stated that on Feb. 28, 1915, while in his ship, he fell down a forecastle ladder, bumping from step to step for a distance of twelve feet, but that no ill effects were noticed till a week later, when he reported sick, as seen above.

He was *x*-rayed at this provincial hospital, and reported to have a fracture of the ilium. On the strength of this report and of the history now given by the man, his case was taken up locally, and application for compensation for injury was made on his behalf to the Admiralty.

The medical department of the Admiralty caused investigation of his case to be undertaken. In addition to the note in the sick-bay records of his ship—that he attributed his pain to " getting his bedding wet "—his messmates and fellow-workers were cross-examined, and none of them could remember his having experienced, or having spoken of, the alleged fall down the ladder. The Admiralty then directed that he should be admitted to the R.N. Hospital, Chatham, for exhaustive investigation.

X-ray examination revealed that the line of fissure seen in the ilium was not a fracture, but was an abnormally large canal for a nutrient artery. There was no evidence of sacro-iliac disease. There was lateral curvature of the lumbar vertebræ to the right, but no evidence of caries of the spine, though there were slight signs of osteo-arthritis of the vertebræ in that region. Clinically this curvature was detected, and it was noted that there was also marked rigidity of the lumbar spine. The further past history was elicited that at the age of ten years he had an attack of typhoid fever, and this was followed by " trouble in his back," and subsequently by the formation of an abscess, which was opened; the scar of this can still be seen. The case was therefore probably one of post-typhoid ' rigid spine,' and his pain was due to a sciatica in combination with the lumbar curvature and rigidity. The history of the case—showing that he walked about for a week after the alleged accident—precludes the question of fracture of the pelvis altogether.

Fig. 265 shows the line approaching the sacro-iliac joint which was mistaken for a fracture. *Fig.* 266, which takes in more of the body of the ilium, shows the characteristic V shape of the two nutrient canals joining; this made it evident that the case was not one of fracture. *Fig.* 267 is of the ilium on the other side of the same patient, and in it the marking is well evident.

The interest aroused by this case caused me to examine others, and *x*-ray negatives were taken of every suitable case that came to the *x*-ray room. In only a very few was a similar condition found in the ilium; but in two or three the marking of the ilium was as noticeable as in the original case.

Further investigations were carried out; a number of ilia were procured and *x*-rayed, and the marking was found to be practically constant, though showing numerous and marked differences in arrangement. The most common marking is that of a V-shaped appearance, situated on the body of the ilium close to the sacro-iliac synchondrosis, and this is practically the only one that

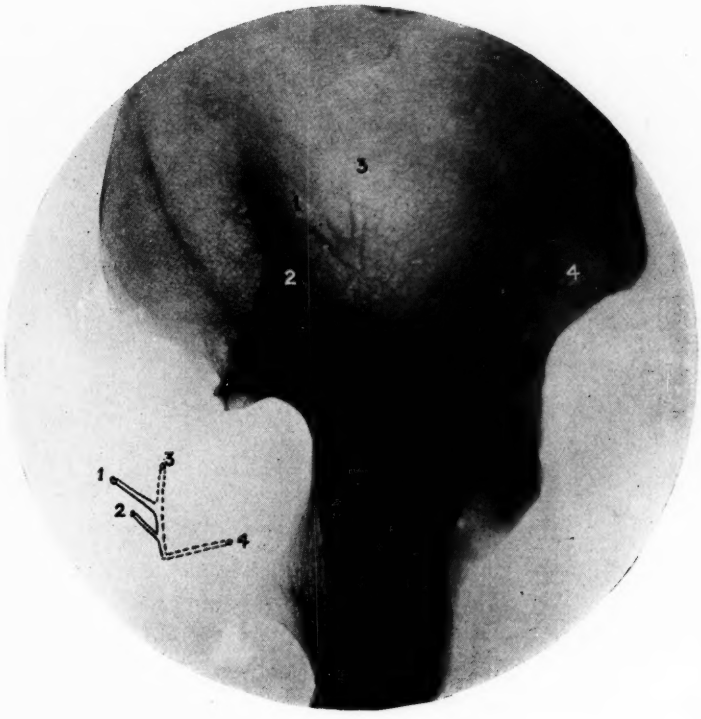

FIG. 268. — Skiagram of left ilium showing two main ventral canals (1, 2) and two main external canals (3, 4). (In *Figs.* 268–273, the solid lines in the diagrams indicate ventral canals, the dotted lines external canals.)

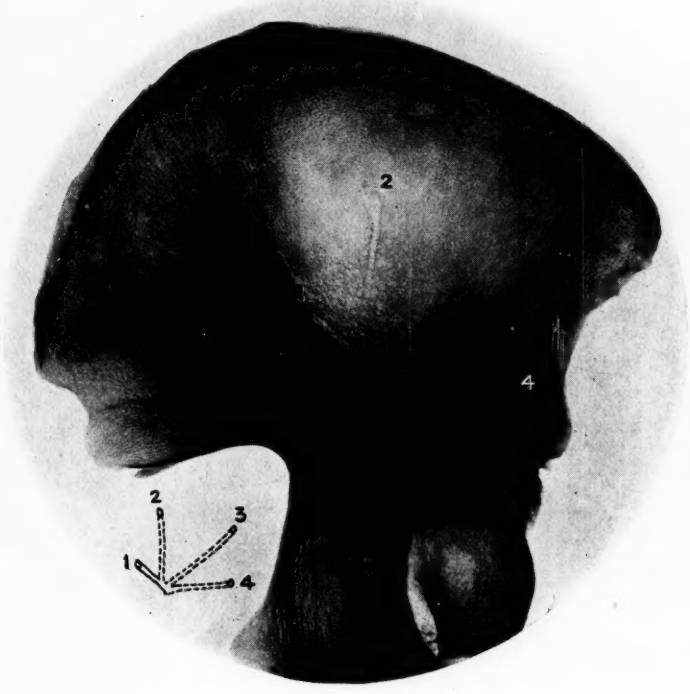

FIG. 269. — Skiagram of left ilium showing one main ventral canal (1) and three main external canals (2, 3, 4).

FIG. 270.—Skiagram of left ilium showing two main ventral canals (1, 2), one being in the sacro-sciatic notch, and three main external canals (3, 4, 5).

FIG. 271.—Skiagram of right ilium showing one main ventral canal (1) and four main external canals (2, 3, 4, 5).

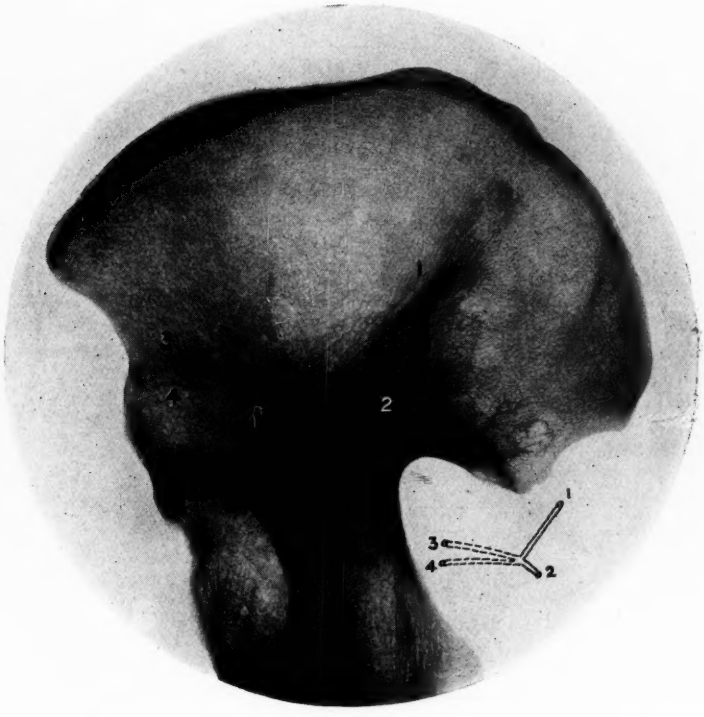

FIG. 272. — Skiagram of right ilium showing two main ventral canals (1, 2) and two main external canals (3, 4).

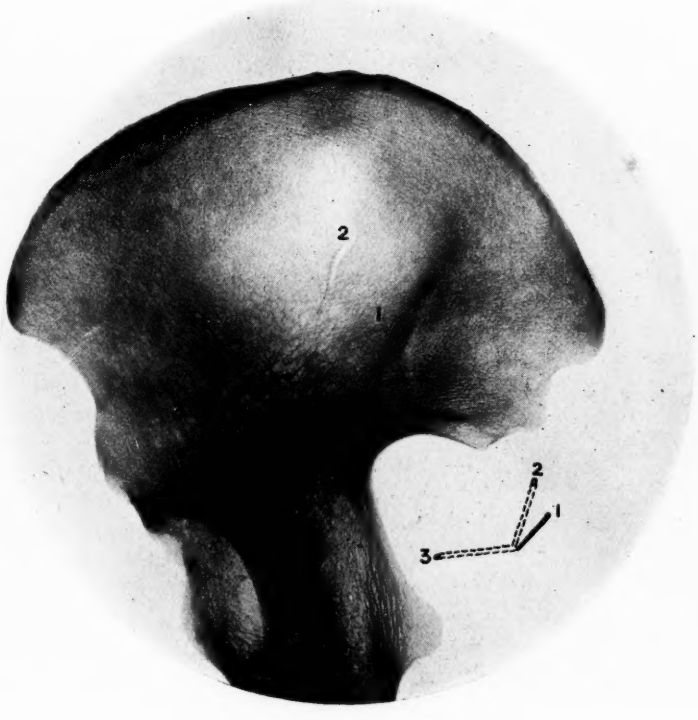

FIG. 273. — Skiagram of right ilium showing one very small ventral canal (1) and two main external canals (2, 3).

FIG. 274.—Skiagram of the ilium shown in *Fig.* 269 after injection with bismuth through the largest foramen. (1) Main ventral canal; (2, 3, 4) Main external canals.

FIG. 275.—Skiagram of ilium with the outer table sawn away to show the common meeting-point of the canals.

is apparent in the ilia *x*-rayed in the living subject. The V-shaped mark represents the canals for the nutrient arteries and their veins. The more central of the arms of the V is found to belong to the canal which gives ingress on the anterior or internal surface of the ilium to the nutrient artery derived from the iliolumbar artery, while the outer arm of the V represents that leading from the foramen on the posterior or external surface of the ilium which is supplied by the nutrient branch of the inferior gluteal artery. At the apex of the V these two separate arteries anastomose, and from that common point send off small branches to nourish the surrounding bone. This common point is situated in the thickest part of the ilium, just above the acetabulum, and above the sciatic notch, and it is reasonable to suppose that this is the true primary centre of the ossification of the ilium. This point of junction is practically constant.

On the other hand, the position and number of the foramina for the entrance of the nutrient arteries show a wide diversity. *On the internal surface of the ilium*, the commonest situation for the foramen appears to be at the lower part of the internal iliac fossa, close to the auricular portion of the ilium which articulates with the sacrum. This foramen is the only one of any size in about 50 per cent of the cases, but it may be double (see *Fig.* 268), or multiple, in which case the canals may be too small to be demonstrated by the *x* rays or by the passing of a bristle. Another position in which an additional or alternative foramen is found is just below the iliopectineal line, above the upper border of the great sacro-sciatic notch (see *Figs.* 270 and 272). This also invariably leads to the common point of anastomosis.

There were 200 ilia examined, and an analysis of the size, number, and position of the foramina in them brings out the following figures for the internal surface of the ilium: The foramina were *large* in 60 per cent, and of these 28 per cent were single, 32 per cent were multiple; they were *medium* in 33 per cent, and of these 6 per cent were single, 27 per cent were multiple; they were *small* in 7 per cent, all being multiple. In about 35 per cent the foramen in the sciatic notch was found—occasionally being the only one of any size on the inner surface of the ilium.

On the external surface of the ilium, there are two main positions for the foramina. The commonest is that mentioned in the text-books, viz., on the convex part of its surface, either just above or below the middle curved line. The other position is below the inferior curved line, close to and posterior to the anterior inferior spine. In each position the canals may be single or multiple, as may be seen in *Figs.* 268 to 273.

The analysis of the 200 ilia examined as above gives the following figures with regard to the external or posterior surface of the ilium: The foramina were *large* in 54 per cent, and of these 49 per cent were single, 5 per cent were multiple; they were *medium* in 20 per cent, and of these 13 per cent were single, 7 per cent were multiple; they were *small* in 26 per cent, all being multiple.

These figures show just what one would expect—namely, that if the canals are of large or medium size, the majority are single or few, whereas if they are small, the majority are multiple—the bone receiving its nourishment either by a few large or by many small arteries.

One of the ilia was injected with a bismuth emulsion, under pressure, into the largest foramen (*see Fig.* 274). The skiagram shows that not only are all the canals continuous through their common meeting-point, but also that small branches are given off in the course of the canals to supply the bone contiguous to them.

Fig. 275 shows an ilium which had the outer table sawn away and the canals laid bare to prove that the latter united at the common meeting-point.

The 200 ilia examined were from a collection in the Museum of the Royal College of Surgeons, which included bones, male and female, of all nationalities and periods, ranging from one of an Egyptian 3000 years B.C. to present-day British specimens. The pelves of gorillas and chimpanzees were also examined, and the canals were present, but appeared to be rather small.

To summarize, this case is of interest in demonstrating that it is possible to mistake an unusually large nutrient artery in the ilium for a fracture of that bone; further, it brings out the fact that the nutrient arteries of the ilium, whatever their point of entry, invariably converge to a common meeting-point, which may be considered the true primary centre of ossification of that bone.

In conclusion, I beg to express my sincere thanks to Professor Arthur Keith for his courteous help, and for the facilities afforded me for examining the specimens in the Museum.

REVIEWS AND NOTICES OF BOOKS.

Tumours, Innocent and Malignant: their Clinical Character and Appropriate Treatment. By SIR JOHN BLAND-SUTTON, LL.D., F.R.C.S. With 380 illustrations. Sixth edition. 8vo. Pp. 790. 1917. London: Cassell & Co. Ltd. 21s. net.

THIS work has long held such a deservedly high place in medical literature that the appearance of the sixth edition after a life of nearly a quarter of a century is of much interest to the large circle of readers who use the book as their standard work of reference. In order to do any justice to the new edition it is necessary to study it carefully and compare it with the last edition, which appeared in 1911. It is then found that the author has not been content merely to add new material, although this has been done to the extent of upwards of one hundred pages, but that he has revised every paragraph with scrupulous care, expunging, modifying, and rearranging, so that the reader fails to find any evidence of the patchwork, and sometimes contradiction, which is apt to creep into new editions. The whole work has a refreshing appearance of youthful vigour about it, with evidence of careful discrimination in the selection of that which is new. The value of Bland-Sutton's *Tumours* has always been largely due to the author's intimate practical knowledge of comparative pathology, and in the new preface reference is very rightly made to the importance of this in an endeavour " to catch the deeper meaning of many tumours." No attempt is made to define the term ' tumour,' but it will be noticed that in the section dealing with cysts and pseudo-cysts the interpretation is made sufficiently wide to include such varying conditions as hydronephrosis, compound ganglion, and hydrocephalus. The reader would regret to lose any of the valuable information in this section, but in a future edition some reduction in this direction might make room for additional matter elsewhere. Of the new material, reference may especially be made to that dealing with the hypophysis—which is illustrated by several new figures—the pineal gland, the thymus gland, and the carotid body. Two new figures are added from a case in which a parathyroid tumour caused sudden death from pressure on the trachea. A useful addition will also be found in the remarks on primary cancer of the lung and bronchi.

The chapter dealing with the cause of cancer has been freely modified, and recent investigations receive due consideration. The author's own view is thus expressed " It (the cause) is most probably a microparasite which stimulates the normal epithelial cells of adult individuals to multiply and produce cancer in the same way that the male gamete or spermatozoon initiates reproductive changes in the female gamete or ovum." Let us hope that the author may live to know whether this view is correct or not.

Throughout the work Sir John Bland-Sutton does not hesitate to express his own opinion on any subject which is debatable, and it may be of interest to note what he has to say upon various matters taken almost at random.

In dealing with the subject of hypernephroma, reference is made to the doubt expressed by Stoerk and others as to the origin of these tumours of the kidney in adrenal rests, and the author shares the opinion that the majority of such tumours are carcinomas arising in the cells of the renal tubules.

It is satisfactory to find considerable scepticism expressed regarding the genuineness of most cases of supposed ' bronchogenous cancer,' and a new figure illustrates a case regarded as one of this nature in which the tumour of the neck proved to be secondary to a growth in the sinus pyriformis.

Most surgeons and pathologists will, we think, agree that, "although adenoma and carcinoma occasionally co-exist in the same breast, an adenoma never becomes transformed into a cancer"; but exception will be taken by many to the statement that "chronic mastitis is a precursor of adenomas as well as a precancerous condition."

In dealing with the subject of rodent ulcer, the author uses the term as synonymous with cancer of the sebaceous glands, but mentions the other views which are held as to the origin of the growth. The description of the histology of the growth is not altogether satisfactory, and the subject is one which seems deserving of at least one illustration.

It is well known that much difficulty is experienced in determining the real nature and origin of the so-called 'renal sarcoma' of infancy, and we must confess that the author's view that the epithelial cylinders in these tumours are due to the entanglement of uriniferous tubules, and that the striated spindles are derived from the muscle-tissue of the renal pelvis, is not quite convincing. Can *striated* spindles be derived from the *plain* muscle fibres in this situation, and how shall we explain the occasional presence of cartilage in tumours of this kind? It seems far more likely that the tumours in question are composite in structure, and that their origin must be sought in some early phase in the development of the part.

In the section dealing with tumours of the testicle, reference is made to Paget's classical case, described in 1855 as a malignant enchondroma, and the subsequent discovery in the tumour of columnar-celled epithelium by Kanthack and Pigg which led them to regard the growth as a carcinoma with cartilage in the matrix. The author might have continued the history of this tumour, by recording the more recent discovery by Nicholson of epithelial pearls in the growth, thus showing that it must be regarded as a teratoma.

The author's views with regard to carcinoma of the ovary and Fallopian tube are well known, and are summed up as follows: "Evidence derived from reports of cases, and my own experience of cancer of the Fallopian tube in which the post-operative histories have been obtained, support the opinion that cancer of the tube, like cancer of the ovary, is almost invariably secondary to a focus in the gastro-intestinal tract." The following practical advice is a natural outcome of this opinion: "In the course of an ovariotomy, if the surgeon encounters a solid or semi-solid ovarian tumour, especially if the tumours are bilateral, this suggests a thorough examination of the gastro-intestinal tract for a primary focus."

This short notice may seem altogether inadequate; but a general review of a work of such established reputation seems quite superfluous; it speaks for itself. The excellent wood engravings, of which eighty are new, and many apt quotations from the poets, help to make our satisfaction with the book particularly complete.

Cerebellar Abscess: Its Etiology, Pathology, Diagnosis, and Treatment. By Isidore Friesner, M.D., New York, and Alfred Braun, M.D., New York. Large 8vo. Pp. 186, with 10 plates and 16 illustrations. 1916. London: William Heinemann. 12/6 net.

This is a short book constituting an epitome of the writings of other people about the anatomy and physiology of the cerebellum in brief, and about cerebellar abscesses in detail. A discernment on the part of the reader that this is the purpose of the authors will leave him satisfied that the task has been well carried out. But should he entertain the hope that such fruits of personal experience are about to be offered as shall aid him to cope with the difficult problem of cerebellar abscess, a good deal of disappointment awaits him. A full description of the authors' experience of even one case would have enhanced the value of the book, whilst the experience of many cases would probably have re-adjusted their own perspective in epitomizing the writings of other people.

The diagnosis of the presence of a cerebellar abscess is a notoriously difficult problem, and few lesions are so elusive. This difficulty is not lessened by a mere recapitulation of every symptom and sign that may or may not be present, and by a laborious extraction of the relative percentages of signs 'present'

or 'absent' in the cases under review. Not even an exact knowledge of the age incidence and the sex frequency of the lesion (pp. 77, 78) is likely to lighten the burden of the surgeon who is confronted with the direct responsibility of the treatment of a case. Consequently, in the chapter on 'Symptoms' no clear impression is made upon the reader of the salient clinical features of a cerebellar abscess, neither is the impression left that a cerebellar abscess frequently has no salient clinical features at all. As a description of symptoms that may be due to any lesion of the cerebellum the chapter is of value, and contains a lucid analysis of Bárány's recent work on spontaneous deviation and induced nystagmus. But the authors fail to point out that these tests are of far more value in cases of cerebellar tumour, and that cases of cerebellar abscess are often far too ill to be submitted to the former one, and are frequently far too young to co-operate intelligently in its execution (they note that cerebellar abscesses are most common between the ages of ten and twenty years). As for induced nystagmus, it has long since lost its value as a precise diagnostic sign, on account of the extreme variability of its response. This aspect is fully developed under the heading 'Differential Diagnosis,' in the sub-section on labyrinthitis, which completely—but possibly unwittingly—discredits the value of the test.

In this same chapter a grave omission from the differential diagnosis of meningitis from cerebellar abscess is made. Meningitis is a very common disease and cerebellar abscess a comparatively rare one, so that one of the earliest and most reliable signs of meningitis ought to be familiar to everyone. *Irregularity of the pulse-rate* is established from the onset in meningitis—a feature of the disease to which Horsley attached the greatest importance, and he repeatedly emphasized its great diagnostic value in his writings. A failure to refer to this sign must be an oversight on the part of the authors. Their statement that "Hysteria may be mistaken for cerebellar abscess" must be accepted as possible, but we think that it would have been more helpful to the reader if it had not been suggested, whilst the inclusion of the differential diagnosis between cerebellar abscess and acute polioencephalitis of the cerebellum would have been a valuable substitute in its place.

The etiology of cerebellar abscess has been collected and analyzed with considerable care from groups of selected published cases, and the authors have done good service in calling attention to its intimate relationship to middle-ear disease. "Ninety-eight per cent of cerebellar abscesses are otitic in origin" is the opening sentence of their preface, and it is probably the most important one in the whole work. It might well be printed in capital letters, and repeated at intervals throughout the book, to indicate in what direction the successful treatment of cerebellar abscess lies. Nearly 90 per cent of those of otitic origin follow upon chronic suppuration of the ear, the small remainder being the sequel of acute suppuration. Now chronic suppuration of the middle ear is a preventible disease, and its existence on a large scale is merely the fruit of indifference to the remote sequels of oral sepsis improperly cared for. With the disappearance of chronic aural suppuration, cerebellar abscesses, with their difficult diagnosis and unsatisfactory treatment (the average death-rate of those operated upon is nearly 70 per cent!), will also disappear, and they may then take their place in the category of preventible diseases. 'Diagnosis' and 'Treatment' are the Dead Sea fruit of surgery when contrasted with the harvest of 'Prevention,' and if the authors' book should serve as a stimulus to thought in this direction, then they have written probably better than they knew.

La Chirurgia degli Organi di Movimento. Edited by Dr. V. Putti. Pp. 159, figures 19. Vol. I, fasc. 1. Price abroad, 35 lire.

This is the first number of a new journal, published in Bologna, and devoted to the surgery of the limbs, or orthopædic surgery, as it has become the custom to call it.

The editor, Dr. Putti, contributes the first and most interesting article, on the operative mobilization of ankylosis of the knee. His method consists in a very free exposure of the joint after division of the tubercle of the tibia and turning aside the patella, and then taking free flaps of fascia lata and covering the raw surfaces of the

femur and tibia. The tendon of the quadriceps is lengthened after a Z-shaped incision. He gives details of six cases, in which all except one acquired from sixty to ninety degrees of movement. The main criticism about this procedure is, that if the bone ends are so widely exposed as to permit of their being enveloped in fascia, this can only be secured by a complete sacrifice of the lateral and crucial ligaments, the absence of which must endanger the stability of the limb.

Other articles are contributed by Dr. Vanghetti on plastic amputation stumps, and by Dr. Delitala on the normal and pathological anatomy of the tarsus in relation to traumatic lesions. Dr. Serra describes some very interesting cases of the transplantation of bone in the human subject, in which he had the opportunity of examining microscopically the grafted area at varying periods after the operation. The pictures of the microscopical preparations are exceedingly clear, and afford a demonstration of the active vitality of the grafted tissue.

The whole publication is well printed and splendidly illustrated, and represents a very real addition to the current literature of orthopædic surgery.

Common Diseases of the Male Urethra. By FRANK KIDD, F.R.C.S. 8vo. Pp. 132, with numerous illustrations. 1917. London: Longmans, Green & Co. 5/- net.

THIS small book is an essentially practical one, dealing with the diagnosis and cure of gonorrhœa and its principal complications in the male. Its chief value consists in the precise directions given as to examination, instrumentation, and the use of irrigation. It is a practical outcome of the study of the "pathology of the living." A valuable feature of the work consists in brief notes of seventy cases illustrating special points of exceptional interest in etiology and treatment.

Notes on Military Orthopædics. By COL. SIR ROBERT JONES, C.B. 8vo. Pp. 132, 128 illustrations. 1917. London: For the Red Cross Society, Cassell & Co. Ltd. 2/6 net.

THIS work, which bears an introductory note by Sir Alfred Keogh urging the importance of orthopædic surgery for the military medical officer, is an attempt to present the general principles of limb surgery in a condensed, authoritative, and clear manner. It is an *ex cathedra* statement in the best sense of the term, that is to say, it is an expression of the clear convictions of its author derived from his own unrivalled experience, and it does not attempt to discuss or deal with conflicting or divergent views. It may be doubted whether the methods which have proved invaluable in the treatment of deformities of children are equally well adapted for application to gunshot injuries. This criticism is particularly apposite in considering the use of the abduction frame for the treatment of high fractures of the femur. The sections dealing with the deformities of the feet and disabilities of the knee-joint are the most valuable in the book, whilst those relating to the treatment of fractures are most open to criticism, on the ground that they do not sufficiently recognize the many difficulties and complications of the subject, and the need for a correspondingly varied technique in treatment.

Medical and Surgical Reports of the Episcopal Hospital, Philadelphia. Vol. III. Pp. 356, 124 illustrations. 1915. Philadelphia: WM. J. DORNAN.

WE heartily congratulate the editor of this volume, Dr. Ashley Ashhurst, on the energy and enterprise which brought together such a large number of valuable papers from the workers of a single hospital during one year. As most of the papers have already appeared elsewhere, usually in one of the American periodicals, it is not necessary to mention them in detail. The most notable contents of the present volume are the articles on modern bone and joint surgery, many of which are by Dr. Ashhurst himself, and those on the diseases of the eye by Dr. Oram Ring.